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Research Article

Performance analysis of hybrid PV-diesel-storage system in AGRS-Hassi R'mel Algeria

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Abstract. The main research paper focuses on the optimal hybrid system using HOMER software in the central plant of Hassi R'mel. Indeed, the system is composed of PV panels, a battery bank, and a diesel engine, all of which are used to supply an industrial load. Hence, the present work proposes a solution to optimize the power generated by the power sources, maximize the photovoltaic source use, and minimize the use of the battery bank and the diesel generator. Moreover, the solution aims to guarantee the safe operation of the system components and continuity in the load power supply. These objectives are performed by the minimization of a cost function, in which the power generation cost, the energetic balance, and the environmental parameters are taken into consideration. Among the five solutions, the most optimal system obtained is PV/Diesel/batteries /Grid. This system consists of 1200 KW PV, an 1100 KW diesel generator, 800 units of battery, and an 1100 KW converter. Therefore, to supply the station with 49% of electricity by PV and 51% by diesel while the reduction of emissions is 60%, and 708020 liters of diesel is saved. Applying the sensitivity analysis also showed that renewable resources have an impact on the sizing of PV. When solar radiation increases, the size of renewable energy decreases and the NPC decreases as well. It can, thus, be illustrated that the PV/diesel/battery system is not fully-optimal. This strategy is recommended for industrial system security since it can be used to ensure systems from an energetic and economic point of view.

Keywords: Hybrid power system, technico-economic analysis, solar PV, carbon emission, Hassi R'mel, Homer

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1. Introduction

In Algeria, like other developing countries, electricity consumption is increasing enormously. This is due primarily to the increase in population, the development needs of industries and the comfort of individuals. In addition, this country with its close position to Europe is an exporter with a promising future via the Mediterranean Sea. An energy transition is underway to meet the demand and conservation of fossil fuels through the use of hybrid systems. In particular, in the industrial zones located in the south of the country, the application of this technique constitutes the way of transition par excellence, in particular in the oil sector. (Sakhrieh *et al*. 2022; Das *et al*. 2017; Raghuwanshi *et al.* 2022; Aykut and Evrard 2017; Rekioua *et al.* 2008; Bentouba and Bourouis. 2016; Dekker *et al.* 2012). The depletion of fossil resources, in the more or less long term, the surge in crude oil prices, and the fight against greenhouse gas emissions (Jahangir *et al.* 2022; Olson and Lenzmann 2016; Abraham *et al.* 2023; Rezzouk and Mellit 2015; Ghezloun *et al.* 2012) make it urgent to control consumption and diversify sources of energy, a fact that challenges the development of renewable energies stronger than ever.

Renewable energy systems represent a prominent alternative to the grid connected systems. The exploitation of renewable resources is growing rapidly in industrialized countries and even in some underdeveloped countries. Focusing on Algeria, a large country with a much-diversified climate, with two distinct geographical zones, the northern Mediterranean and the southern Sahara, can become an excellent competitor in this race for recourse to renewable energies, (Stambouli 2011).

Algeria's solar potential is considered as one of the most important potentials in the Mediterranean, and the exploitation of this source could help save oil and gas, considering that solar and wind energy is technically feasible.

Algeria has launched in 2011 a national program to develop renewable energy based on photovoltaics (PV), concentrated solar power (CSP), and wind power, and to promote energy efficiency. The program consists of installing up to 12 GW of power-generating capacity from renewable sources to meet the domestic electricity demand by 2030, (Bouklia and Mecibah 2013). Laissaoui *et al.* (2017) combine a CSP with multi-effect desalination.

An integrated solar combined cycle power station near Hassi R'mel began producing electricity in June

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2011. This first hybrid plant combines a 25 MW parabolic trough concentrating solar power array that covers an area of over 180,000 m^2, in conjunction with a 130 MW combined cycle gas turbine plant. This could reduce carbon emissions compared to a traditional power station. The output from the solar array is used in the steam turbine. Further to the south, electrification of Assekrem is by photovoltaics within the scope of the Algerian-Spanish cooperation. Assekrem is located in the Atakor, central part of the Hoggar Mountains, which rise to the greatest heights of Algeria (Hamidat *et al.* 2007).

However, a transient energetic period should be assumed between the actual energetic state and the full renewable energy state, in which suitable solutions are required. In this respect, many studies on hybrid energy systems have been accomplished (Mallek *et al.* 2022; Ur Rashid *et al* 2022; Rice et al. 2023; Mouheb *et al.* 2012; Saheb-Koussa *et al.* 2011).

The hybrid system has a double advantage in order to minimize environmental disturbances through consumption in t he place of production of renewable natural resources and security of supply, whatever the weather is like. The published review shows the importance of the hybrid renewable energy system, (Maouedj *et al.* 2015; Labriet *et al.* 2000; Bahramara *et al.* 2016; Heinbockel and Roberts 1977; Baneshi and Hadianfard 2016; Saheb-Koussa *et al.* 2010). Particularly, studies are presented by Amani *et al.* (2020) and by Aouadj *et al.* (2021) for integrated solar combined cycle systems of Hassi R'mel.

Before any implementation of a renewable energy system, a technical and economic feasibility study is necessary to justify the investment and the budgets allocated. There are many studies about the optimization and sizing of hybrid renewable energy systems. Different approaches were presented by (Erdinc and Uzunoglu 2012; Leon *et al.* 2023, Khrisna and Kumar 2015; Lian *et al.* 2019)

There are many computers aided design methods to analyze and evaluate the hybrid systems. Among these programs, HOMER is a user-friendly computer tool that is effectively used to develop the models of the power systems for economic and technical analysis; it also allows comparison of different designs.

Many studies have been done and reported in recent literature about the evaluation and the analysis of PV/diesel/battery hybrids**.** Thirunavukkarasu and Sawle (2020) designed and proposed an optimal sizing of a standalone hybrid system. They found that the PV/Diessel/Converter provides optimal results. Halabi *et al.* (2017) presented a performance analysis of a hybrid system in Sabah-Malaysia, where the hybrid PV/Diesel/ Battery system is believed to be the best technical performance compared to all other scenarios. Chouaib *et al.* (2017) sized an optimized hybrid central content among three different systems, two renewable energy (solar photovoltaic and wind power) and two nonrenewable (diesel generator and storage systems). The best ecological and economical configuration for the isolated village in southwest Algeria is the usage of 2,500 kW solar photovoltaic energy, two wind turbines, 1,400 kW diesel generator and 2,400 kW storage system (battery); the hybrid central is over 83% based on renewable energy.

The favorable context and an important source of experience in solar energy techniques at Hassi R'mel allow the application of a PV-diesel storage system. In this paper, the authors suggest a technique-feasibility investigation for electric power which is a novelty for a central station in Hassi R'mel. The size of such an energy production system depends essentially on the consumption profile to be met. The power demanded by an outbreak of a given nature is not fixed throughout the year. The time of maximum loading of the energy system by the load varies according to the seasons due to the variation of the duration of the day. Moreover, in the context of the current study, only the electrical demand is considered. This energy is used for lighting purposes and industrial utilities by ensuring the operation of the turbines, compressors, and all those whose operation depends on electricity. This work aims at revealing the optimal sizing depending on different designs, and reducing the cost parameters. Applied to the recovery (AGRS-Hassi R'mel) station, energy savings and stable operation of the equipment are expected.

2. Methodology

2.1 Hassi R'mel field

In this study, the proposed system is considered for Hassi R'mel which is located in Laghouat Province, 60 kilometers (37 mi) northwest of Ghardaïa, in the northern-central part of Algeria, Fig.1. According to the geographical location, the site is located at latitude 32° 55′ 41″ north 32◦ 928' N, longitude 3° 16′ 16″ E, and 264 m altitude above sea level. Hassi R'mel has a desert climate. Throughout the year, rain is technically non-existent. According to Köppen and Geiger, the climate is classified BWh. Over the year, the average temperature in Hassi R'mel is 18.9 ° C. The average annual rainfall reached 110 mm.)

The development of Hassi R'mel has been linked to the development of the gas industry in the world. For this reason, an Associated Gas Recovery Station (AGRS) was carried out for the collection of the associated flared gases previously at the oil treatment centers (OTC-1/2/3/4).

The AGRS has two purposes: the first one is economic, represented in the recovery of gas rich in LPG, and the second one is environmental, represented in the suspension of flaring by contributing to the company's environmental policy, Fig.2. This

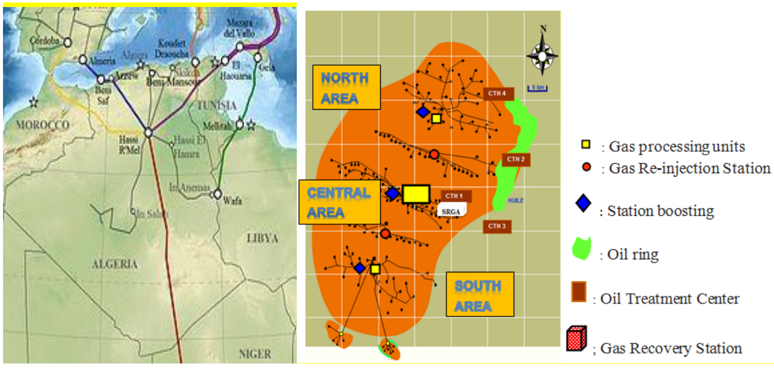


Fig. 1 Location and industrial centers of Hassi R'mel region

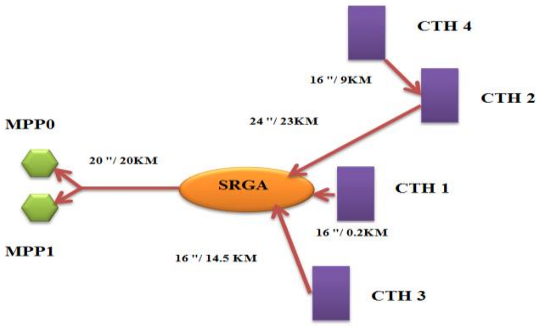


Fig. 2 Connection diagram of the CTH and modules with the station

station has a need for power to ensure the running of a daily energy of 469 kWh.

2.2 Proposed solutions

Among the major problems of the called AGRS station is the high cost of electricity consumption. It consumes around 469 kWh. Therefore, in order to ensure this energy level that allows the station's equipment to work properly, and in order to avoid repetitive cuts in the currents (three to five times a day), some alternative solutions are proposed. Thus, the PV- diesel system which minimizes the diesel load is proposed, knowing that solar panels do not require extensive maintenance. Adding more battery strings would allow optimisation of the usage of excess electricity and to increase the overall autonomy of the PV-diesel system. In this case, the spinning reserve is not needed to absorb the irradiance variations in the plant because the batteries supply the necessary power when PV generation decreases due to passing clouds. Any excess in electricity produced is fed back into the grid by a PV-batteries- diesel grid system, earning income from the excess power generated.

2.3 The optimized system specifications

- *The system design*

In order to design PV/ batteries/Diesel/grid hybrid power system by using HOMER software, one has to provide some inputs such as hourly load profile, monthly solar radiation value for a PV system, the initial cost of each component (renewable energy generators, diesel generators, battery, converter), cost of diesel fuel, annual real interest rate project lifetime, etc. The considered system is schematized in Fig.3 and the proposed diagram is in Fig.4.

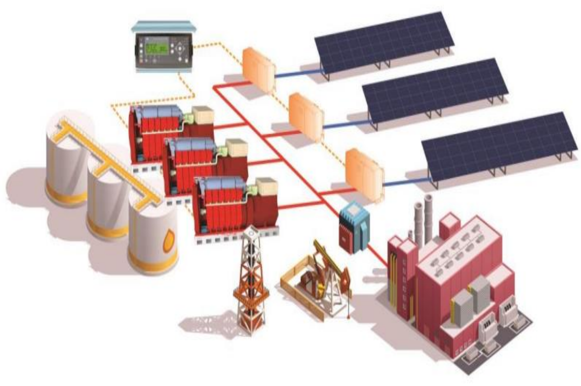


Fig. 3 Schematic diagram of the considered system

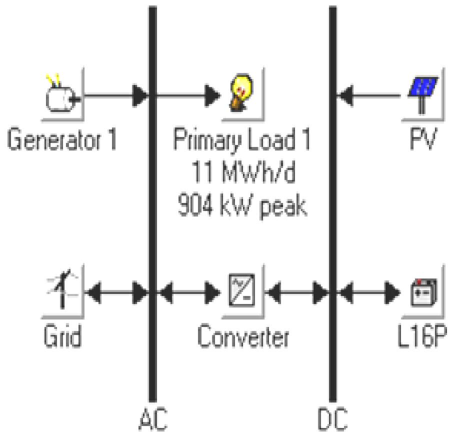


Fig. 4 The system diagram as realized in the software

The software simulates 8,760 hours in a year. After simulating all of the possible system configurations, HOMER presents a list of feasible systems, classified by lifecycle cost.

- *Theoretical background*

The Hybrid Optimization Model for Multiple Energy Resources (HOMER), is a micro pro software which can contribute to solving electrical supply solutions (Balachander *et al.* 2021; Basheer *et al.* 2022; Khalid *et al.* 2023). This tool facilitates the periodic evaluation of the efficiency, sustainability, and importance of electric power projects, including assessing both off-grid and grid-connected power systems. This software will be used in this study not only for its ability to calculate the energy balance of an electrical system, but also offers a number of configurations. Consequently, a combination of these configurations is possible for the sake of optimality. All the solutions are sorted by the net present cost (NPC), so an easy comparison between the proposed solutions quickly leads to an optimal choice.

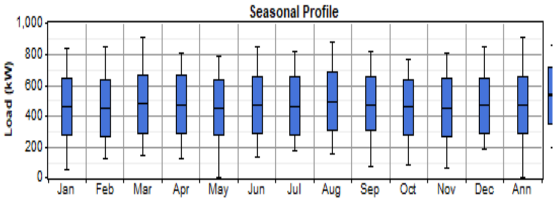
So, it's used here to optimize the best energy efficient system for (AGRS) station in Hassi R'mel considering an industrial load and PV-Batteries-Grid-Diesel combination and is based on the solar resources (Yakub *et al.* 2022; Hidalgo *et al.* 2022; Naderipour *et al.* 2022).

- *Electric load and solar radiation data*

A typical industrial load system for the (AGRS) station in Hassi R'mel in a remote area in Algeria with real load data provided by the plant managers for one whole year has been considered in the present case analysis. As input, monthly average hourly load demand has been taken into account. It has been found that for this system, the user consumes energy around 469 kWh/day with a peak demand of nearly 904 kW. The daily load in summer and winter is shown in Fig. 5 a.

In the area of the present study, the solar data are obtained from the National Office of Meteorology (ONM 2015), the annual average solar radiation is 6.23 k Wh/m^2/d and the highest radiation in May is 8.493 kWh/m^2/d. The least solar radiation in December is 3.332 kWh/m^2/d. As shown in Fig. 5 b, the red line is the clearness index which is equal to the global solar radiation on the surface of the earth divided by the extraterrestrial radiation at the top of the atmosphere.

a) the load daily profile.



b) the solar profile

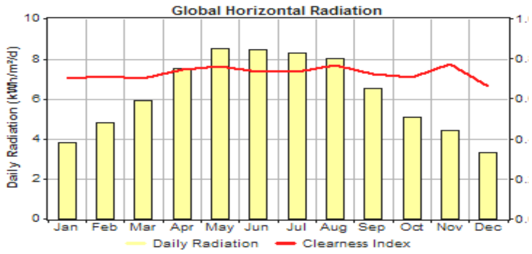


Fig. 5 a) the load daily profile and b) solar radiation data

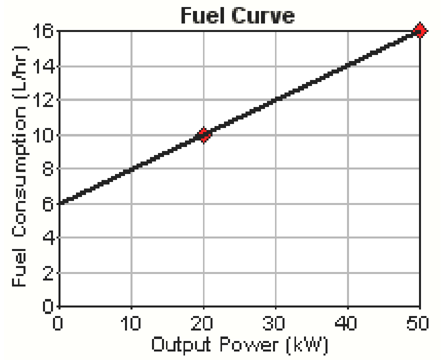


Fig. 6 The fuel curve plotted by HOMER

Table 2
Specification of diesel generator

Diesel generator capital cost	2550 $/KW
Diesel generator replacement cost	2550 $/KW
Diesel generator O&M cost	0.150 $/hr
Lifetime	15000 hr

2.4 Mathematical model and economic details of the system components

A further detailed mathematical model of the components of the proposed hybrid system (PV, DG, grid, batteries, and converter) and the control strategy can be found in previous works of literature. However, a succinct summary of each mathematical model and economic parameters is presented as follows:

- *PV module*

Photovoltaic panels were specified with capital and replacement costs (Issahaku and Kemausuor 2022; Arsyad *et al.* 2022; Tay *et al.* 2022; Chel *et al.* 2009). This cost includes shipping, tariffs, installation, and dealer markups (Table 1). Some maintenance is typically required on the batteries in a PV system, but very little is necessary for the panels themselves. A de-rating factor of 80% was applied to the electricity production from each panel. This factor reduces the PV production by 20% to approximate the varying effects of temperature and dust on the panels. The panels were modeled as fixed and tilted south at an angle equal to the latitude of the site. So, the power output of the PV panel is given by equation 1.

$$P_{pv} = Y_{pv} F_{pv} \left(\frac{G_t}{G_{tstc}}\right) \quad (1)$$

Where Y_{pv} is the rated capacity of the PV array, meaning its power output under standard test conditions [kW], F_{pv} is the PV derating factor [%], G_t: is the solar radiation incident on the PV array in the current time step [kW/m^2], G_{tstc} is the incident radiation at standard test conditions [1 kW/m^2].

In this study, the specifications of the PV Module are given in the Table 1 In this case, six different types of PV arrays are considered to get the optimal size (0, 2, 5, 7, 8, 9, and 10 kW).

Table 1
Specifications of PV Module

PV capital cost	3500$/kW
PV replacement cost	3500$/kW
PV O&M cost	0 $/yr
Slope	32.91
De-rating factor	80%
Life time	20 years
Azimuth	0

- *Diesel generator model (DG)*

The diesel generator system is designed to supply the load and provide battery energy storage if the PV energy along with the battery or the grid is unable to supply the load. So, the power output of the DG is proportional to fuel consumption FC (L/h), Fig 6, given by equation 2:

$$F_G = F_{Gi} P_{Go} + F_{Gs} P_{Gou} \quad (2)$$

Where P_O is the nominal power of the DG on kVA, P_{GOU} is the output power in kVA; F_{Gi} and F_{Gs} represent the coefficients of the fuel consumption curve defined by the user (l/kWh**)**
Furthermore, the specifications of the chosen DG are given in Table 2

- *Converter*

The proposed hybrid system contains both the AC and DC system. Furthermore, the inverter is necessary to maintain the flow of power between the system and the load. The overall characteristics summary of the chosen converter is given in Table 3.

- *Battery energy storage*

Batteries accumulate excess energy produced by the PV system and store it to be used when there is no other energy input. The total amount of energy stored in the battery at any time is the sum of the available and bound energy, hence:

Table 3
Specification of converter

Converter capital cost	1000 $/KW
converter replacement cost	1000 $/KW
converter O&M cost	100 $/yr
Lifetime 15 years	15 years
Inverter efficiency	90 %
Rectifier efficiency	85

Table 4
Specification of battery

Battery capital cost	735 $/kW
Battery replacement cost	735 $/kW
Battery O&M cost	2 $/yr
Nominal voltage	6 volts
Nominal capacity	360 Ah
Lifetime throughput	1.075 kWh
Type	Trojan L16P

$$Q = Q_1 + Q_2 \quad (3)$$

Where Q_1 is the available energy and Q_2 is the bound energy.

Now, we introduce the overall characteristics as specified and shown in Table 4. The software considers each quantity in the size for returning the optimal system.

- *The grid*

The grid input in the software has three tabs:

- Rates, where the cost structure of grid power was defined;
- Emissions, where the emission factors in the grid power were defined.
- Advanced, where certain advanced variables are set.

The overall characteristics summary of the grid is given in table 5.

2.5 System control parameters

System control parameters define the operation of the battery and generator in the hybrid system, economic inputs play an integral role in the entire simulation and optimization process. Whereas, the constraints were a set of predefined conditions which the systems must fulfill.

- *Simulation time set*

The simulation time step is the time step used to simulate the operation of each system configuration. The time for simulation can be entered from several hours down to one minute. In the system, the duration of the simulation is set to 1 hour.

Table 5
Specification of the grid

Capital cost	8000($/kW)
O&M cost	160$/yr/km
Grid power price	0.1($/kW)

- *Dispatch strategy*

A dispatch strategy is a set of rules used to control the operations of the generators and the battery bank whenever there is insufficient photovoltaic energy to supply the load. Two types of dispatch strategies are available in HOMER, namely; cycle charging and local following strategy (Ajao *et al.* 2011; Salam *et al.* 2013; Olatomiwa *et al.* 2015a; Tazvinga *et al.* 2013; Tissot 2001). Under the cycle charging strategy, the generators operate at their maximum rated capacity to serve the load and charge the battery bank using excess power. On the other hand, of the load-following strategy, generators produce only enough power to serve the load and do not charge the battery bank. Both Strategies depend on various characteristics including the size of the generators and battery bank (Allouhi and Rehman 2023; Li *et al.* 2022; Olatomiwa *et al.* 2015b), the O & M cost of the generators, the price of fuel, and the photovoltaic power fraction in the system. In the present study, both strategies are considered, which income HOMER after simulation to determine the optimal configuration.

2.6 Economics inputs

- *The levelized cost of energy*

The levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced (Nässén and Larsson 2015; Silva *et al.* 2013; Nacer *et al.* 2014). To calculate the COE, it divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total useful electric energy production. The equation for the COE is as follows:

$$COE = \frac{C_{an,tot} - C_{boiler}E_{thermal}}{E_{prim,AC}+E_{prim,DC}+E_{def}+E_{grid,sales}} \quad (4)$$

Where

$C_{an,\,tot}$: total annualized cost of the system [$/yr]
C_{boiler}: Boiler marginal cost [$/kWh]
$E_{thermal}$: total thermal load served [kWh/yr]
$P_{rim,\,AC}$: AC primary load served [kWh/yr]
$P_{rim,\,DC}$: DC primary load served [kWh/yr]
E_{def}: deferrable load served [kWh/yr]
$E_{grid,\,sales}$: total grid sales [kWh/yr]

- *Total net present cost*

The total net present cost of a system is the present value of all the costs that it incurs over its lifetime, minus the present value of all the revenue that it earns over its lifetime. Costs include capital costs, replacement costs, operation and maintenance costs, fuel costs, emissions penalties, and costs of buying power from the grid. Revenues include salvage value and revenue from network sales.

The total net present cost is calculated using the following equation:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i,R_{proj})} \quad (5)$$

Where:

$C_{an,\,tot}$: total annualized cost [$/yr]
CRF (i, R_{proj}): capital recovery factor
i: interest rate [%]

R_{proj}: project lifetime [yr]

- *Constraints*

Constraints are conditions that systems must satisfy. Discarded systems do not appear in the optimization results or sensitivity results that do not satisfy the specified constraints.

The renewable fraction is the portion of the system's total energy production originating from renewable power sources. HOMER calculates the renewable fraction by dividing the total annual renewable power production (in our case the energy produced by the PV array) by the total energy production, the equation for renewable fraction is:

$$f_{ren} = \frac{E_{ren}+H_{ren}}{E_{tot}+H_{tot}} \quad (6)$$

Where:

E_{ren}: renewable electrical production [kWh]
H_{ren}: renewable thermal production [kWh]
E_{tot}: total electrical production [kWh]
H_{tot}: total thermal production [kWh]

2.7 Sensitivity procedure

The HOMER software will perform the iterations to get optimal result for every selection including sensitivity variable for the hybrid renewable energy system. The sensitivity variables are such as the global solar, and cost of diesel fuel. Then, a list of various system configurations of designed hybrid renewable energy can be presented in tabulation form considering cost wise analysis lowest to the highest NPC. The optimal solution means a hybrid renewable energy system having lowest NPC.

When the analysis involves more than one sensitivity variable, a graph often conveys the results in a more meaningful way than a table can. The optimal system type (OST) graph gives the highest-level view of the sensitivity results.

3. Simulation results and discussion

3.1 Scenarios ordered by the total NPC

The result panel shows the list of configurations available based on the input data introduced and ordered by the total NPC (Net Present cost). It is possible to display the entire list of configurations or to show only the best solutions (from an economic perspective) per system design. In the present case study, the categorized list displays five different configurations, ordered by most effective NPC, as follows in Table 6.

The choice of the right configuration is a complex trade-off ranging from financial, renewable, Technical to design requirements. The second scenario represents the Diesel system (baseline model) only with the maximum net present cost which is equal to 22,365,540 $ as a result of operation, maintenance, and fuel costs. This diesel system is needed to quantify the impact of addition of other components. It is obvious that 0% renewable penetration will be obtained here compared to the total renewable scenario (hypothetical model) with PV and without DG.

From Table 6, it is observed that the optimal hybrid system (second scenario), consisting of a 1200 kW PV, diesel generator of 1100 kW, 800-unit battery, and 1100 kW converter under solar radiation of 6.22 KWh/m²/d and the diesel price based on 1 $/l. This hybrid system shows the lowest total net present cost (21,822,950 $) with an initial capital cost 6,446,765 $. The operating cost is 1.693,965 $/yr. The cost of energy is 0.590 $/KWh, the renewable fraction (RF) is 0.49 and the dispatch strategy is cycle charging.

The third result is the PV-Diesel-Converter system, including a 1400 kW PV system, 1100 kW diesel generator, and 1100 kW converter with a net present cost of 24,529,792 $. The operating cost is 1,979,834 $/yr, the cost of energy is 0.663 $/KWh. Although the renewable fraction obtained by this system is 0.49, this scenario cannot be retained because of the relatively high NPC. It is clear that the impact of injecting the PV panels in the first part and the batteries in the second part play a vital role in the economics performances and the stability of the hybrid systems. However, Table 6. shows that the hypothetical system (PV-B-C) is not economically viable.

3.2 Characteristics of the best configuration

The cost summary displays the initial, replacement, operating, fuel, and salvage costs for each component. The highest cost is 13,695,602 $ for a diesel generator as it requires a lot of operating and maintenance costs (1,568,719$) and the fuel cost is (9,995,150$). Fig.7 shows the cash flow summary for PV/Diesel/Battery and converter system.

The analyzed data presented in Fig. 7 indicates that the fuel consumption represents nearly 50% of the NPC and the addition of the PV panel constitutes 25% of initial capital. So, these two elements dominate naturally the net present cost. It should be noted that the COE is almost equal for all systems except the diesel-free system.

Excess electricity for this system is 683,410 KWh/yr which represents 13.7%; the non-satisfied electric load is 0.00287

Table 6
Results for the five solutions

System	PV-D B-C	D	PV- D C	D B-C	PV B-C
PV(kW)	1200		1400		3000
Diesel (kW)	1100	1100	1100	1100	
Battery (unit)	800			80	1600
Converter (kW)	1100		1100	1100	1100
Capital cost (M$)	6,447	0,559	6,558	1,718	23,360
Total NPC (M$)	21,823	22,366	24,530	24,780	37,618
COE ($/kWh)	0.59	0.605	0.663	0.67	1.017
RF (%)	0.49	0.00	0.49	0.00	1.00

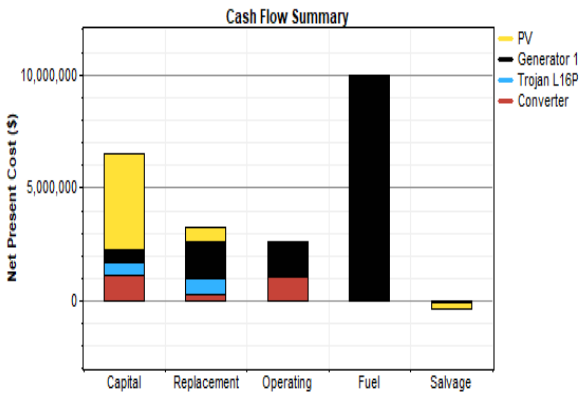


Fig. 7 Cash flow summary

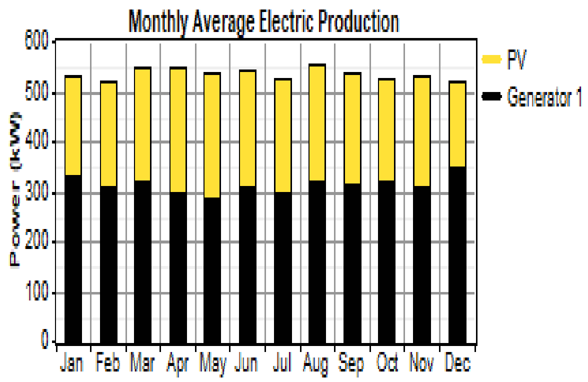


Fig.8 Monthly Average Electric Production

KWh/yr and the capacity shortage is 0 KWh/yr. This is a shortfall that occurs between the required operating capacity and the actual amount of operating capacity which the system can provide. The total production of the PV is 2,443,170 KWh/yr with penetration equal to 49%, and the operating hours of the PV are 4,389 hr/yr.

Finally, the total production of the diesel generator is 2,536,142 KWh/yr with operating hours equal to 5,258 hr/yr, and the fuel consumption is 1,096,740 l/yr. The operational life of the diesel is 2.85 yr. For example, the share of the diesel generator 51 % is shown in Fig.8

As shown in Fig.8, the highest PV energy production is during April, May, June, July and August due to the high solar radiation in these months. The last diesel production is in the months of April, May, and July, due to the decrease in load in comparison to other months in summer and winter. However, electricity production is practically shared between diesel and PV, Fig. 8. As expected, only in December and February, the total

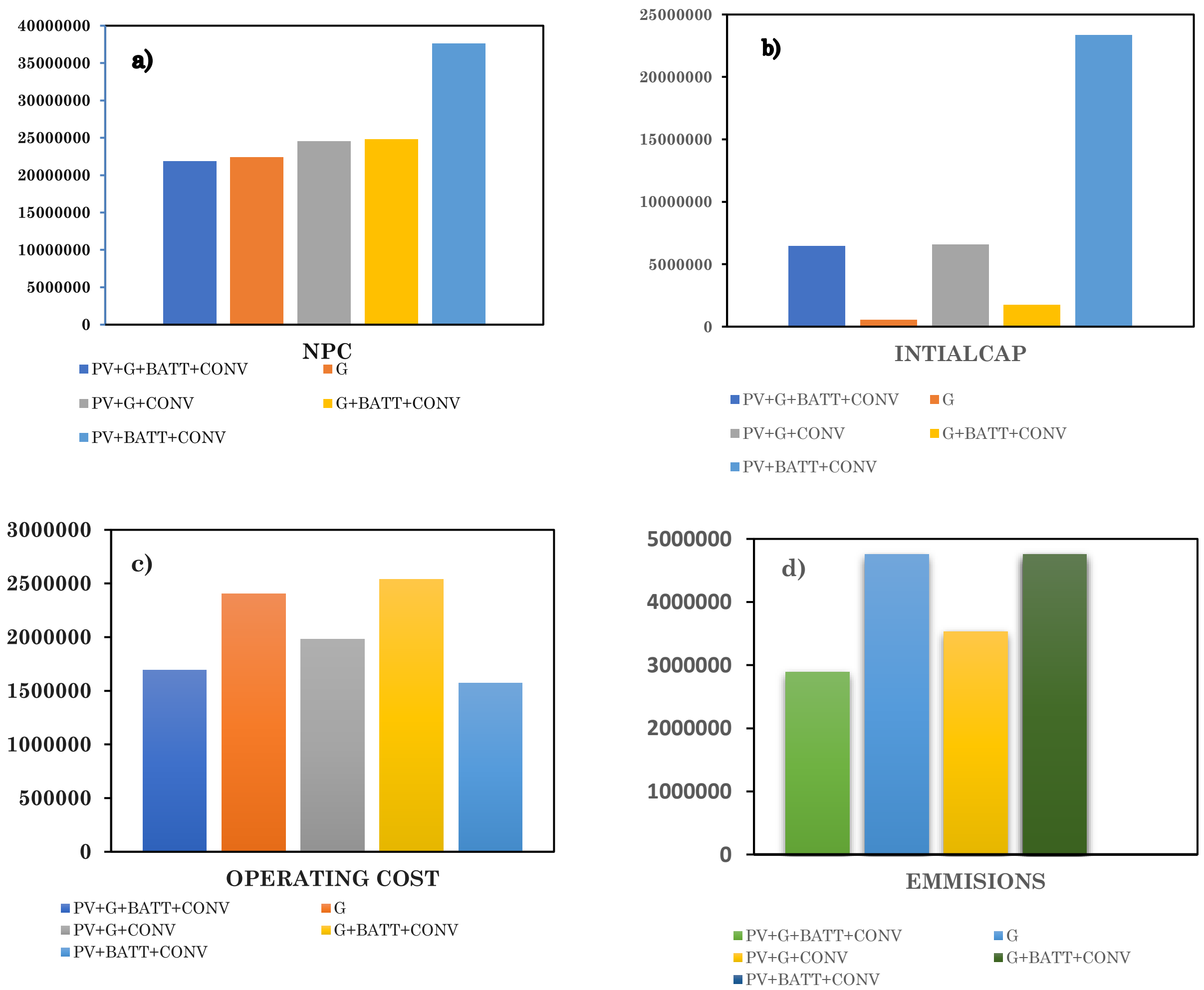


Fig.9 Net present cost ($) initial cost ($), operating cost ($/yr), and emissions (kg/yr) for different systems

production is less compared to the other months, according to the solar profile, Fig. 5b

Figure 9 is then prepared to highlight all the costs and emissions for a practical view, allowing a comparison of the considered hybrid systems. According to the net present cost, the minimum cost is generated by the PV-G-battery-converter system, then the G system, While the maximum cost, on the other side, is generated by a PV-battery-converter system operating without G as shown in Fig.9. This is because the components like PV, battery, and the converter are still expensive. In a perspective of the hypothetical system or pure solar system, this requires a great initial investment compared to a diesel system. These results prove once again the interest of hybrid systems where free solar energy greatly amortizes the costs. The non-hybrid system (G) has an NPC comparable to the optimized one, but the fuel consumption is high with an unfavorable ratio when the fuel price increases.

At present, and as shown by the initial cost plot (Fig 9), it is not yet possible to eliminate diesel generation in high-performance systems. All systems have similar operating costs and are, therefore, not indicators for choosing the best configuration. This is explained by the low maintenance costs observed.

Emissions have a very negative impact on the environment and result from fuel consumption (Marneni, *et al.* 2015; Shakya *et al.* 2022; Ali *et al.* 2023; Adetoro *et al.* 2023; Diab *et al* 2016). Carbon emission quantity is considered about 99.5% of CO2 emission of the total exhaust of fuel carbon.

By carrying out a comparison between the five systems, it can be found that maximum emissions resulted from systems operated only by G system and by G-battery-converter system (4,752,966 kg/yr) due to the fuel consumption and emissions after the transformation of heat energy into electrical energy in diesels. The PV-G converter system has an emission of order 3,531,538 kg/yr. There are no emissions produced in the PV-battery system as the renewable resources are clean and environmentally friendly as shown in Fig 9, and the emissions are low in this case (2,888,078 kg/yr).

4. Sensitivity analysis

According to the conditions, an optimized system was identified. Some factors such as diesel price, solar radiation, PV cost and battery costs are variable. Then, it is necessary for the selected system to be a subject of sensitivity analysis. The variables that are chosen to be displayed in the sensitivity analysis are solar radiation and diesel price shown in Table 7.

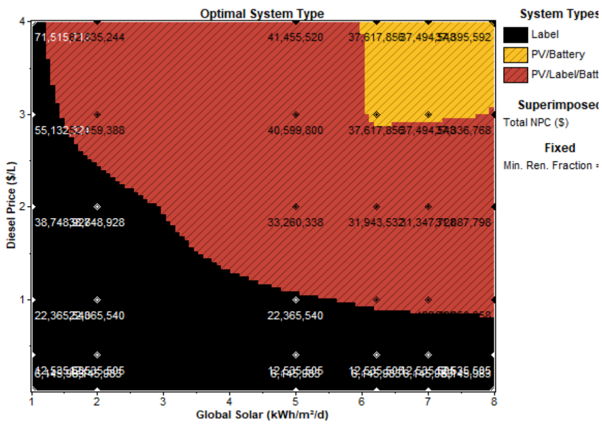


Fig.10 Optimal system type

4.1 *Impact of altering solar radiation and diesel price on optimal system type*

The Figure 10 shows the results from the sizing study, after having simulated all the possible configurations. The figure shows that under the load conditions, cost of components and availability of resources presented earlier, the optimal or least expensive system includes PV, Diesel and batteries when the price of fuel exceeds $0.8/l (the illumination is set at 4.8 kWh/m²/d).

In many developing countries, currency exchange fluctuations have a strong impact on diesel prices. It is currently fluctuating around 2.08 $/l. Diesel prices are expected to increase due to high global demand while PV and battery prices are expected to decrease due to the current technological development. Considering the annual average solar radiation 6.23 kWh/m²/d, the hybrid system begins to be justified for a diesel price 0.8 $/l. Above this last price, solar hybrid system is requisite. Beyond a diesel price 3 $/l, pure solar system with a battery becomes the only alternative regarding the economics. In the same figure, one can obviously see that poor global solar, at every site location, leads to non-economic PV panel installation. These trends can be explained logically by the dominance DG system with low diesel price and global solar. It should be noted here that the system becomes costly with a high diesel price. Systems without DG become attractive with the high fuel price and global solar.

4.2 The impact of altering solar radiation and diesel price on the net present cost.

Sensitivity analysis also allows the optimization results to be applied to more than one facility, without having to run new studies for other locations. Fig. 11 shows that the total NPC can be kept low even with high levels of solar radiation if diesel price is maintained at low levels, and moderate NPC can be seen up to 2 $/l diesel price. This trend remains uniform for more diesel prices, except for the lowest global solar values where high NPC can reach values close to 80,000,000 $. This can be explained by the expensive diesel price together with the capacity of PV installed in a bad solar location. These results are in a good agreement with (Olatunji *et al.* 2022).

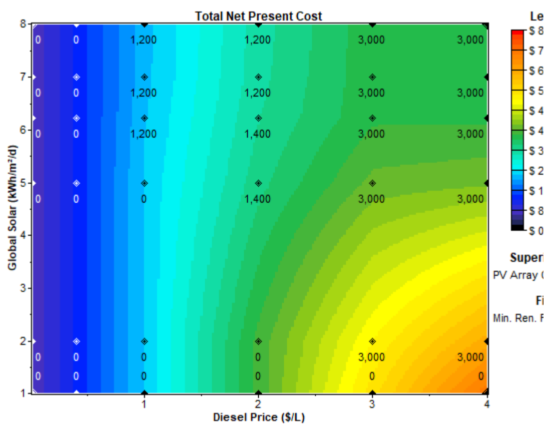


Fig.11 Total net present cost as a function of solar radiation and diesel price at Min. Ren. Fraction equals 0%

Table 7
Variables for sensitivity analysis

Solar radiation (KWh /m²/d)	**1**	**2**	**5**	**6.22**	**7**	**8**
Diesel price ($/L)	0.01	0.4	1	2	3	4
Min. Ren. Fraction (%)	0	20	30	50		

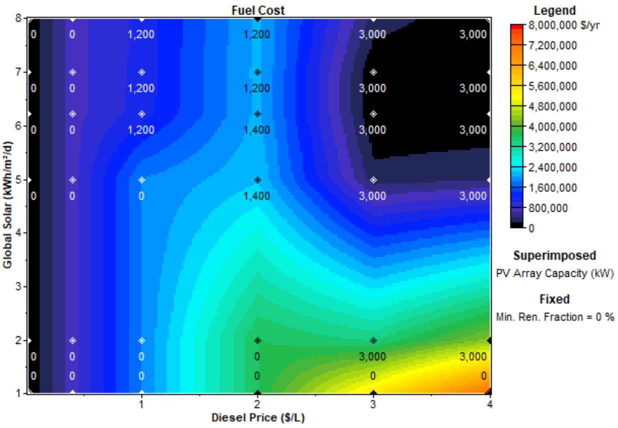


Fig. 12 Fuel cost as a function of solar radiation and diesel price at Min. Ren. Fraction equals 0%

4.3 The impact of altering solar radiation and diesel price on fuel cost

On the other hand, changing the diesel price will have a great impact on fuel cost as shown in Fig.12. For an average solar radiation above 5.5 kWh/m²/d, it is clearly visible that two zones can be distinguished separately. The fuel cost remains low until the diesel price reaches 2 $/l, and in contrast, if the diesel price increases, there will be a sudden change towards the lowest fuel cost.

5. Conclusion

This study reveals how the technical application of a hybrid power system, which consists of PV/Diesel/batteries/Grid for industrial application, is deployed to feed the AGRS station with electricity

The modeling and simulation of the project are done by HOMER software whereas the most optimal system is PV/Diesel/batteries /Grid. This system consists of 1200 KW PV, a 1100 kW diesel generator, 800 units of battery, and a 1100 kW converter. Therefore, we can supply the station with 49% of electricity by PV and 51% by diesel, while the reduction of emissions is 60%, and also 708020 liters of diesel is earned.

The sensitivity variables of this simulation are solar radiation and diesel price. By applying the analysis, it showed that renewable resources have an impact on the sizing of PV. When solar radiation increases, the size of renewable energy decreases and the NPC decreases. It can, thus, be illustrated that the PV/diesel/battery system is not fully-optimal. The economic system in this case is PV/diesel/battery system at any value of solar radiation and diesel price. Also, diesel price has no effect on the configuration of the whole system, but it can result in some additional costs if oil prices blow out in the market.

This study can be applied at any factory or plant in the world according to the site location as it depends basically on solar radiation in the chosen area. Hence, the significant contribution of this work is to demonstrate that solar energy can be exploited in the south of Algeria, leading to economic interest. Moreover, it can cut down the emissions on the environment as well as minimize the huge consumption of this non-renewable source of energy (fuel). These alternative ways instead can provide the station with electricity through clean technology, and ensure that the operations of the CPF (central processing facility) will be uninterrupted. From this contribution, the best objective function result obtained are

- the high renewable fraction obtained in one par tto supply the station with 49% of electricity by PV and 51% by diesel while,
- in a second part, the reduction of emissions about 60%, and 708020 liters of diesel is saved.

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