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Optimization Study about a Hybrid Energy System (solar PV and wind) to Supply a Habitat Located in an Isolated Area in Algeria

Maamar Mouheb [1,*], Ahmed Fellah [1,2], Mohamed Amine Khorchef [1], Bendaoued Bencherki [3]

[1] Mechanical department, University Ahmed Zabana, Relizane, Algeria
[2] IS2M Laboratory, Faculty of Technology, University of Tlemcen, Algeria
[3] Department of mechanics, Faculty of Technologies, University of Chlef, Algeria

Abstract: Generation of energy from renewable resources is mainly implemented to supply to remote rural areas. In this context, we attempted to exploit the renewable energy (especially solar and wind power) that characterizes a remote and isolated site in Algeria, which also benefits from motivating tourist characteristics, our aim is to develop the site through supplying habitats with clean and free energy and reducing greenhouse gas emissions. For this purpose, we suggest the installation of a hybrid energy system (PV, wind and diesel), and we will do an optimization study about the feasibility and ability of the proposed system to meet the energy needs without the need to store energy to reduce the cost of installation, this work is based on a real case study and the simulation results obtained by HOMER show the effectiveness and the flexibility of the proposed system against to load variations while ensuring better stability.

Keywords: Hybrid system; Renewable energy; Solar photovoltaic; Wind power; Solar energy.

1. Introduction

We all know that energy is very important to everyone's life, but energy needs of all kinds are growing everywhere on the world. The announced depletion of fossil fuels and climate problems due to greenhouse gases has led several countries to give high priority to this issue.

There are different types of energy, but electric energy is the most important that people need every day. It is the easiest form of energy to harness today, but before consuming, we have to think about how to produce it, generally in high-power electricity production units, how to transport it, and then how to distribute it to each consumer. All this will increase the financial burden for the electrification of isolated sites. Electric energy from renewable sources (photovoltaic; wind turbine; geothermal, etc.) is a good solution for these areas.

A hybrid elective energy generation system becomes a remarkable choice to overcome the supply problems of isolated sites, the combination of several sources generates a particularity and their operation too. The diversification in terms of energy sources for this system remains a major advantage to limit the problem of fluctuation of renewable sources. However, their installation requires a sizing study of the components representing the system to define an ideal operation.

A hybrid system means a power generating system which combines two or more different sources of energy; this system can use different energy sources such as wind, photovoltaic, and diesel generators. In spite the lack of continuity and difficulty in predicting the productivity of some renewable energy sources, it is possible to integrate

*** Corresponding author:** Maamar Mouheb, ***E-mail address:*** *mouhebmaamar@yahoo.fr*

sources that complement each other, such as solar energy and wind energy, as the efficiency of the system will improve significantly.

This type of system may represent a solution for remote areas. The duty of a hybrid system is not only to bring "an energetic power", but a tool of social and economic development for the farming zones.

Several papers studied the hybrid system; Dekkiche et al. [1] are interested about the ability of a hybrid power system PV-Wind-Diesel with storage (batteries) to cover the need for electric consumption in an isolated site, within the Chlef region, Algeria. Al-Ghussain et al. [2] seek to determine the optimal size of a PV/wind/biomass hybrid system with and without energy storage built on the base of the need production fraction and the fraction of renewable energy. Eisapour et al [3] propose a resilient smart hybrid renewable energy system to cover the electricity and heat need of Eram Campus, Shiraz University in Iran, in this work, simulations, optimizations, and sensitivity analyses are performed to explore the feasibility of using a unique integrated energy system to cover the load need of the case study. Sifakis et al [4] present a paper about an applied assessment framework to provide insights into the design and the optimal sizing and control of a hybrid renewable energy system into seaports, ensuring operational stability and safety. The proposed framework provides a reliable, cost-effective, and sustainable solution for a large Mediterranean port's power supply. It is also highly replicable regardless of the port's size. Sharma et al. [5] propose a novel dynamic multi-objective receding horizon strategy for operational optimization of medium-scale hybrid renewable energy system, this candidate system under consideration involve a solar PV cell, wind energy, diesel generator, and hydrogen storage. As an extension to classical receding horizon strategy in which only one objective is used, three non-commensurate objectives are optimized simultaneously to obtain the optimal control variable trajectories. The objectives considered in the optimization problem are minimization of the system operating cost, minimization of the power from non-renewable energy resources, and minimization of the fuel emissions. A popular evolutionary algorithm, genetic algorithm, is used for solving the multi-objective formulation. Further, the efficacy of the developed approach is illustrated by comparing its performance with interior point method. Amarsingh B. Kanase-Patil et al. [6] present in their work which focuses on how we use hybrid renewable energy to meet the energy needs of an educational building. They propose a combined system of photovoltaics (PV), wind turbines, and biogas plants. Singh A.et al. [7] provide review of various research work done for finding solution for rural electrification using hybrid energy systems in India. This work is done on the basis of cost analysis, unit sizing optimal designing, control and optimization, and pollution reduction. Also, feasibility of a system with different combinations of renewable sources has been presented.

Also, we can cite several studies for isolated regions all over the world have been made such as the study of Onar et al. [8] in Turkey, Rehman et al. [9] and Elhadidy and Shaahid [10] in Saudi Arabia, Nfah et al. [11] in Cameroon, Asrari [12] et al. in Iran, Missoum et al. [13] in the North-West of Algeria, Bentouba and Bourouis [14] in south of Algeria.

Algeria is a vast country in Africa and there are rural communities located in isolated and mountainous regions. Currently, the diesel generator is the most used technique for the electrification of remote sites. However, the access to these sites is generally difficult, as such the costs of maintenance and fuel supply is very high. The exploitation of renewable energy resources (solar and wind) in combination with a diesel generator to produce electricity proved to be the most cost efficient in isolated regions where the given the random nature of resources and the variation in their deposits from one region to another, the most promising solution is the use of hybrid energy systems.

Through this work, we want to supply a well-defined load on a specific site with energy from the combination of wind and photovoltaic. Our purpose is to find a balance between energy supply and demand (the load). Also, we will interest about the minimization of system cost while maximizing the system reliability, minimization of the power from non-renewable energy resources, and minimization of the fuel emissions.

2. Case Study

2.1. Description of the chosen location

The chosen site is an isolated area located in the northwest of Algeria in the near to the Gargar dam of Oued Rhiou wilaya of Relizane, there geographical coordinates are 35° 56'45 "N in latitude and 0° 59'33" E longitude. This remote site is a tourist site characterized by beautiful landscapes, calm zone, and clean air. In order to exploit all these qualities, we propose to install a hybrid energy system to cover the energy needs of a leisure habitat. The location of our site is shown in Figure 1.

Figure 1: Location of the studied site.

2.2. Solar potential

Knowing that the energy production of PV panels depends essentially on solar irradiation, so solar irradiation data is very important in determining the amount of electricity generated by PV.

Our site is a sunny area all year round; there is no obstacle in front of the system. By using the Meteonorm software, we can have several data of the solar field, concerning the site concerned. Figure 2 presents the horizon and the course of the sun during the four seasons of the site.

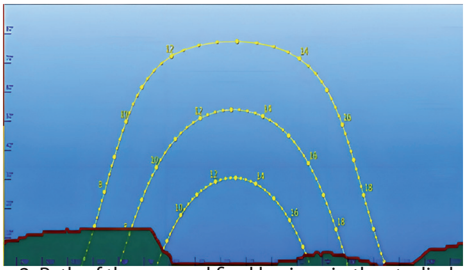

Figure 2: Path of the sun and final horizon in the studied site.

Figure 3 presents the insolation duration, we can easily see that our site is characterized by very long insolation duration, it exceeds 7 hours during almost the whole year, also it is maximum during the whole summer period, which favours us the use of solar radiation received.

In Figure 4, we present the monthly solar irradiation estimates by an inclined plane at the optimal angle, we find that our site receives a quantity of solar energy exceeds 120 kWh/(m2*month) during the most of the months of the year.

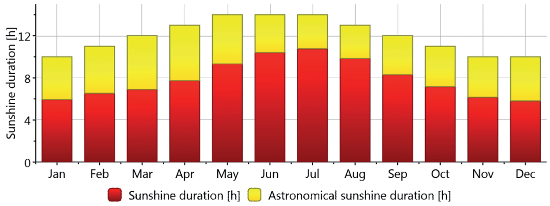

Figure 3: Sunshine duration concerning our site.

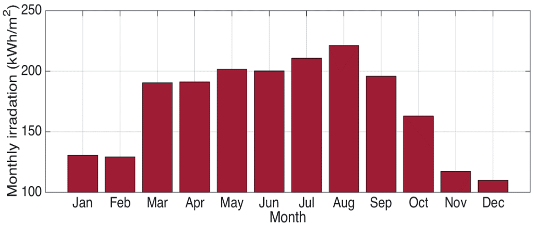

Figure 4: Monthly solar irradiation estimates.

For more details about the solar potential that characterizes our site, we will present the solar data for this region, obtained from the site of evaluation of the solar field PVGIS, which estimates the solar radiation of several cities according to location, inclination and orientation.

We show in Figure 5 and Figure 6 that our site receives an interesting amount of solar radiation, the power is maximum during the summer period especially in July when it reaches: 7 (kWh/m^2/d). The most unfavourable month is December when the radiation cannot exceed: 3.5 (kWh /m^2 /d).

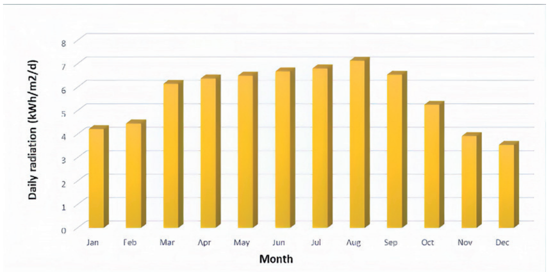

Figure 5: Daily solar radiation received by our site.

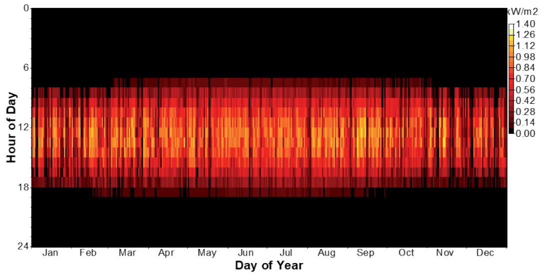

Figure 6: Global solar radiation incident throughout the year by the studied site.

2.3. Wind energy

The homer software presents us data concerning the wind deposit. Our site receives an acceptable amount of wind, where it peaks in May and June when its speed reaches 3.9 m/s. The unfavourable month is January, where the wind speed cannot exceed 2.5 m/s (Figure 7).

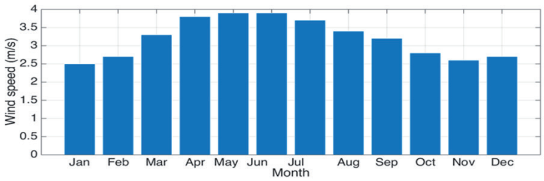

Figure 7: Monthly wind speed for the studied site.

3. Evaluation of Consumption

The proposed hybrid system is assumed to cover the energy needs of a house located in the area we are studying, inhabited by about five people, in order to spend a vacation in this place. The dimensioning of such system depends essentially on the consumption profile to be satisfied.

In order to cover the energy needs of our living habitat, we propose that the habitat consists of three rooms, and, we only consider the demand for electrical energy that can be used for lighting, refrigeration or household purposes, so the most frequently used equipment are limited to: lighting, refrigerator, television, hair dryer, iron, and telephone charger.

We will work for a typical day in August when energy consumption will be maximum, Figures 8-9 present the daily and monthly profile of consumption given by Homer software.

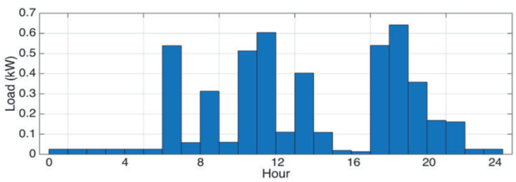

Figure 8: Hourly daily consumption profile.

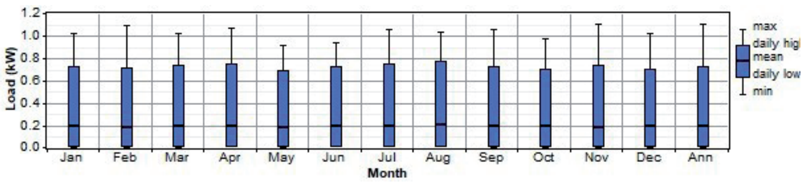

Figure 9: Average consumption for each month.

4. Modeling of the Proposed Hybrid System

The essential functionality of a HRES (hybrid renewable energy system) is the combination of two or more renewable energy generation technologies to expand their operating characteristics and increase efficiency above the efficiency of a single power source. The configuration of the hybrid PV-wind-diesel system using HOMER software based on the user inputs of loads, components costs, components technical details, Solar and Wind resources availability.

The following figures show the components of the hybrid system, as shown in these figures; our hybrid system will be made up of three components, and the produced energy will come from three sources:

- *Solar PV energy.*
- *Wind power.*
- *Generator as back-up.*

Our aim is to supply a specific load on a specific site with energy from the combination of wind and photovoltaic. The problem is to find a balance between energy supply and demand (load) which is a function of time (day, season and year). Each energy source: wind power and solar radiation, varies depending on the time of day, season and year.

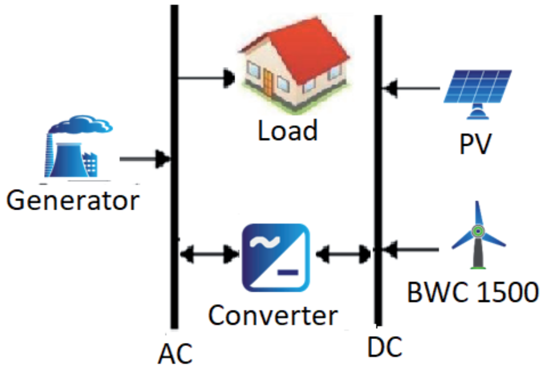

Figure 10: Components of our hybrid system.

4.1. PV Generator Model

The sizing of PV systems is always confronted with two essential criteria that are the solar potential and the load, between which are the conversion and regulation devices to manage the energy involved. The PV module power production has a direct proportion to the solar radiation [15].

$$P_{PV}(t) = P_{Peak}\left(\frac{G(t)}{G_{\text{standard}}}\right) - \alpha_T\left[T_c(t) - T_{\text{standard}}\right] \quad (1)$$

Where: P_{peak} - Power of the PV in standard conditions (W); $G(t)$ - solar radiation (W/m^2); $G_{standard}$ - The solar radiation value according to the standard testing conditions; α_T - PV module temperature coefficient; $T_{standard}$ - The solar cell temperature value according to the standard testing conditions; T_c - The solar cell temperature, which is given as [15]:

$$T_c - T_{ambient} = \frac{NOCT}{800}G(t) \quad (2)$$

NOCT: Nominal operation cell temperature value.

HOMER software uses the ambient temperature to calculate the PV cell temperature; the results are presented in figure 11 we show that the cell temperature was high in the summer, which influenced negatively on the PV modules production power, and was low in winter.

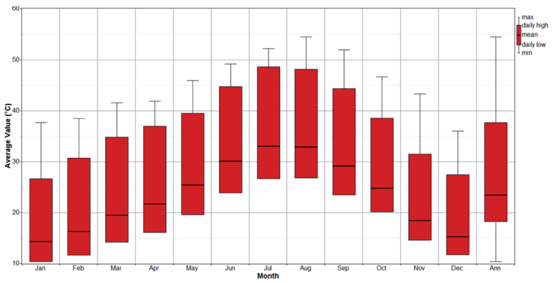

Figure 11: PV cell temperature monthly averages.

The solar modules are mounted at a fixed tilt angle of 35° (latitude of study site) facing true south for maximizing the average annual power output. The characteristic of PV used in the proposed hybrid system are presented in Table 1.

Table 1: Characteristic of used PV.

Size(kW)	Capital ($)	Operation and maintenance ($/year)
1	640	28

4.2. Modeling of the wind energy conversion system

The efficiency of a wind farm depends on the quality of the winds blowing over the region. The energy produced from wind turbines is proportional to the cube of the wind speed. Thus, a 5% increase in wind speed results in approximately 15% increase in the theoretical maximum power that can be drawn from the wind.

In this part, we will focus on determining the average annual power supplied by a wind generator. The kinetic energy of an air mass m moving with velocity v, is:

$$E_c = \frac{1}{2}mv^2 \quad (3)$$

The average wind power available, associated with the circulation of an air mass at a speed v and acting on a surface A, of the wheel of a wind turbine, is written [16]:

$$P = \frac{1}{2}\rho A v^3 \quad (4)$$

Where: ρ designates the density, a parameter varying with altitude and temperature, but generally considered to be constant and approaching on average 1.25 kg/m^3. The previous expression shows that the available power varies with the mean cubic wind speed. The latter is determined from a statistical processing of the raw wind data [17].

The wind generator turbine (BWC 1500 Output) operating parameters are shown in the following Table 2.

Table 2: Characteristic of Wind turbine used in our system.

Quantity	Rotor diameter (m)	Rated power (W)	Capital ($)	Operation and maintenance ($/year)
1	1.15	400	300	50

4.3. Diesel generator

The diesel generators are generally used as back-ups to supplement the lack of energy. Apart from the price of diesel generator, the price of diesel fuel greatly influences the cost of the component; this cost includes price fluctuations, transportation, operation and maintenance costs. The price of diesel is set at an average value of 0.18 $/L (Table 3). Also, to reduce the cost of the kWh produced (improve efficiency), the generator must be used close to its nominal power (Figure 12).

Table 3: Characteristic of diesel group used in our system.

Size(kW)	Capital ($)	Operation and maintenance ($/hr)
1	1386	0.047

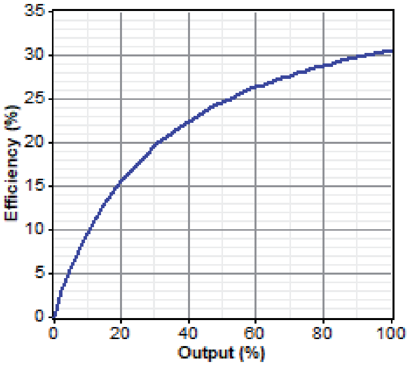

Figure 12: Relationship between the power produced by a diesel generator and its efficiency.

5. Results and Discussion

To simulate the proposed system, Homer 2.81 is used. This software is developed by the US National Renewable Energy Laboratory. It serves to minimize the cost and time of analysis of power systems and the design of different facilities (HOMER will attempt to simulate a viable system for all possible combinations of the equipment that we wish to consider).

HOMER produces calculations to seek the best combination for a hybrid power system meeting the technical and economic specifications required by our site. After the injection of the data presented previously in the HOMER software, the simulation offers us the following cases shown in Figure 13, we will choose the optimal case that is framed in red.

According to the simulation, the total cost of the system will be 31.964 $, and the cost of the kWh produced will be 1.597 $; more details on each system are shown in Figure 14.

The amount of the power electrical energy produced by each component of the proposed system during each month is presented in Figure 15.

Solar panels (PV): The power of produced electrical energy begins after sunrise at any time, between (6 a.m. and 8 a.m.), in autumn and winter, and between (5 a.m. and 7 a.m.) in spring and

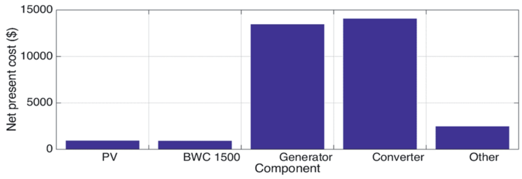

Figure 14: Summary of cash flow.

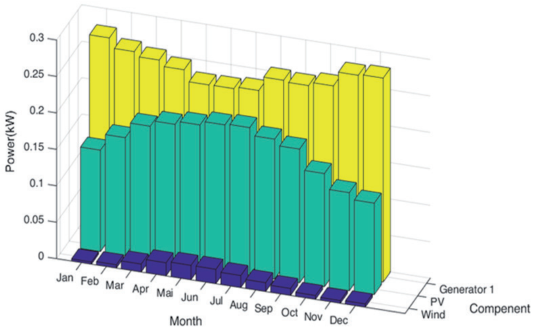

Figure 15: Monthly amount of produced power by each component of the hybrid system.

summer in a very small amount about (0.1 to 0.3 kW) almost zero. But after this time, since (10h and 11h) it increases between (0.3 and 0.6 kW), and will reach at noon its peak of (0.9 kW), finally, it will decrease gradually or even non-existent at sunset, either between (4 p.m. to 5:30 p.m.) in each of the two seasons, winter and autumn, and between (5 p.m. to 7 p.m.) in summer and spring (Figure 16). For a total running time of 4387 h/year at a price of 0.0557 $ / kWh.

Wind turbine: Electricity wind production is low in winter because the wind is limited between 10 a.m. and 6 p.m, compared to other months of the year in which the production changes 0-0.160 kW, and has reached the highest value in May and June (around 19.8 kW) (Figure 17), for a total of approximately 4155 hours/year and a cost of 0.874 $/kWh. According to these obtained results, the amount of energy produced by this source is

	PV (kW)	AIR	GD (kW)	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	jatropha oil (L)	GD (hrs)
	1		1	15	CC	$ 17,235	1,216	$ 31,183	1.558	0.40	1,102	6,667
	1	1	1	15	CC	$ 17,535	1,258	$ 31,964	1.597	0.42	1,087	6,590
			10		CC	$ 16,349	14,113	$ 178,218	8.906	0.00	13,575	8,759
		6	10	15	CC	$ 30,869	12,875	$ 178,545	8.922	0.02	12,033	7,764

Figure 13: Calculation results for the hybrid system.

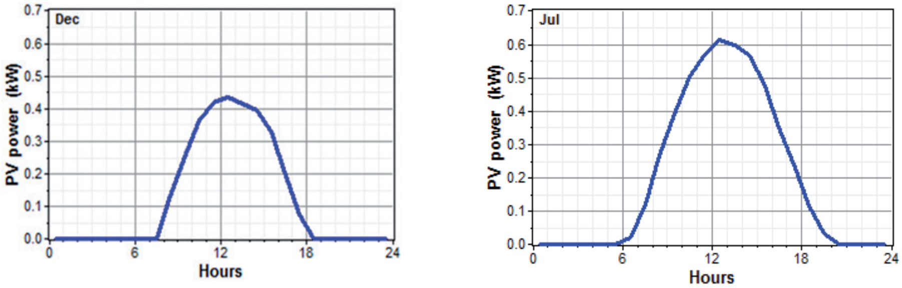

Figure 16: Hourly profile of PV production in Dec. (unfavourable month), and in Jul. (favourable month).

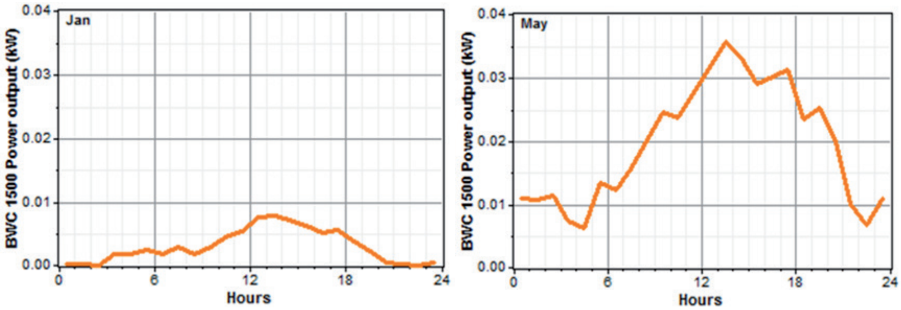

Figure 17: Hourly profile of wind turbine production in Jan. (unfavourable month), and in May (favourable month).

insufficient to meet energy needs without forgetting the cost of the wind system which will therefore increase the cost of the kWh produced.

Now, we will be interested in determining the renewable energy portion produced by our system, for this the homer software presents us in Figure 18 the monthly profile about the power (PV+Wind) produced. This diagram shows us that the renewable production is acceptable during almost all of the months except the winter months (Nov., Dec. and Jan.), so this period does not only correspond to a decrease in insolation, but also in the wind deposit, which affects the renewable fraction produced.

Diesel group: The analysis of the production time of electrical energy at diesel generator is found to be nearly the same Figure 19 throughout the year. It begins at the end of the day (at sunset) and continues until sunrise due to the lack of renewable energy (sun and wind).

The DG produces between 0.5 and 0.97 kW in the period between 7 p.m. and 6 a.m. and from 0.3 to 0.4 kW in the rest of the day to reach 6590 h/year for a consumption of 0.485 L / kWh.

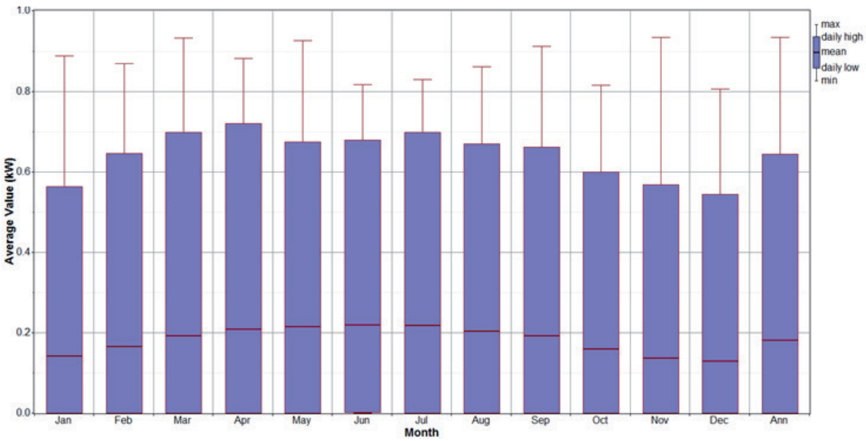

Figure 18: Renewable power (PV+Wind) output monthly averages.

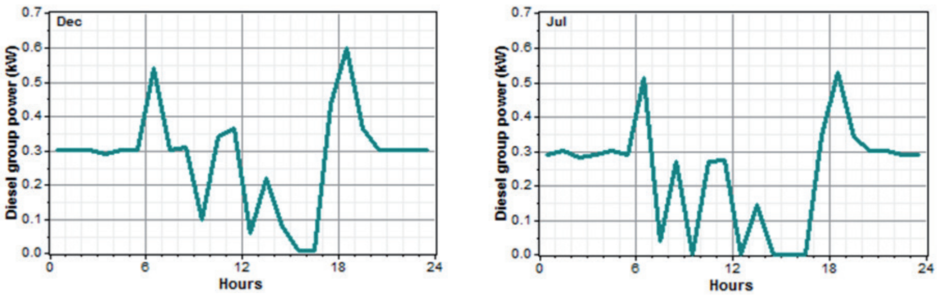

Figure 19: Diesel group electrical output daily production in Dec. and in Jul.

6. Conclusions

In this work we were able to study the electricity production of a hybrid system for the production of electricity from a renewable source. The results obtained were very encouraging for the use of this type of energy.

The goal of our work is to exploit an abundant, clean, free and renewable energy deposit for a site located in a very important place, within the framework of sustainable development, so we proposed the use of a hybrid systems to answer the energy needs of a leisure habitat located in this isolated and remote site, with the objective of maintaining a high level of reliability at a minimum cost thanks to an optimal sizing of hybrid systems, thus in order to reduce greenhouse gas emissions.

The simulation results show us that the proposed system was able to cover the energy needs of the site interested in our study, the production of the PV system was remarkable and very important, during most of the year, this is due to the large deposit that characterizes this site, which increases the profitability of our system. However, the production of the wind turbine is almost negligible, because the wind energy deposit at our site is very low, which increases the cost of our system.

For the DG, this back-up system was able to cover the site's energy needs, especially at night, when renewable production is almost zero, knowing that the cost of fuel is very low.

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