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Optimal design of hybrid energy system with PV-Wind-Battery-Diesel generator energy system: Setif case

Abd Essalam BADOUD *

Automatic Laboratory of Setif, Electrical Engineering Department, University of Setif 1, Algeria
E-mail(s): badoudabde@univ-setif.dz

* Corresponding author, phone: 00213 672 879 920, fax: 036 849 920

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Abstract

In most isolated regions, the diesel generator is the main source of electrical power. The price of the extension of the electrical network for these regions is difficult and costly. These regions suffer from the fuel supply and its high cost, which drastically increases their isolation. In this context, the integration of one or more renewable energy sources can have a beneficial impact on the production of electrical energy, in terms of cost and availability. However, improvements in the design and operation are always necessary to make this technology more competitive in isolated regions. The objective of this work is elaborate of models in view to the sizing of hybrid photovoltaic-wind energy system with storage, to reach this stage of sizing we treat all system parts photovoltaic, wind and diesel; for each subsystem a detailed model was developed followed by validation in the PSIM environment. To maximize the performance of renewable energy systems it is necessary to track the maximum power point MPPT. The sizing of a hybrid system using Homer software is also treated in this work.

Keywords

Hybrid power system; Renewable energy; Photovoltaic; Wind; Optimization; Sizing

Introduction

With about 1.3 billion people in the world without access to electricity in 2010 [1], [2], the global challenge of providing reliable and cost-effective services remains one of the major challenges facing the world in this century. Although grid extension still remains the preferred mode of rural electrification [2], an extension of the central electricity grid to geographically remote and sparsely populated rural areas can either be financially unviable or practically infeasible [3].

In remote regions, electric energy is usually supplied by diesel generators (DG). In the most cases, supplying demand energy using diesel fuel is so expensive and increases the amount of CO2 emitted. Thus, the hybrid system PV-wind- battery- diesel becomes competitive with the only diesel generator [3]. Further, the use of a single renewable energy source such as wind or solar energy is inadequate to meet the demand for long periods due to the high cost of system as well as storage subsystem [4], [5].

Renewable energy based system viability is limited to the resources available at certain location such as solar irradiation, wind speed, diesel price etc. Besides, feasibility study performed on Algeria is limited. Although some locations of southern part of Algeria are covered in the previous studies, this cannot be generalized to the whole of Algeria as there are places with different situation. These locations may be potential to set up Renewable Energy based system, as they may have usable renewable energy resources. In this study, a rural location called Setif in northern part of Algeria has been chosen, where sufficient renewable energy resources are available to set up a hybrid system.

The design of hybrid renewable energy systems requires appropriate dimensioning in terms of power as well as suitable choice of the system components according to the available resources. For this reason, simulation software packages constitute an essential tool for the analysis and the comparison of different combinations and alternatives.

Analysis must take into consideration three main constraints: First, the available renewable resources in a given region. Second, the load profile and last the availability of financial resources [6]. Recently, [7] proposed a hybrid power system to generate power for grid connected applications in three cities in Iraq. Results showed that it is possible for Iraq to use the solar and wind energy to generate enough power for villages in the desert and rural areas. (Nfah, et al [8] studied a solar/diesel/battery hybrid power system to meet the energy requirements of a typical rural household in the range70-300 kWh/yr and found that a hybrid power system was comprising a 1440 Wp solar PV array and a 5 kW single-phase generator operating at a load factor of 70%, could meet the required load. Saheb-Koussa, et al [9] designed a wind/PV/diesel hybrid energy system with battery backup and conducted its techno-economic feasibility for remote applications in Algeria.

HOMER software is a user-friendly micro power design tool that simulates and optimizes stand-alone and grid-connected power systems. Recently, it is has been used widely in the field of renewable energy [10]. The advantage of the HOMER is that it can involve also all costs such as the initial capital and the maintenance costs including pollution penalties.

In this work the optimum system configuration is defined by economic feasibility analysis and finally the different aspect of the system is discussed.

The aim of this paper is the optimization of a hybrid PV-wind- battery- diesel system applied in term of technical and economic feasibility by simulation using HOMER. A comparison was made between the performance of wind/pv/diesel system and the classic connecting system in Algeria.

Materials and Methods

Site and data description

To study the climate of a region, several data are needed such as humidity, sun, snow and others. Knowledge of these factors is required because it affects human activities and their consumption of production and energy habits in particular.

Setif is located in the north of Algeria, with more precision at 530 east (longitude) and 3592 north (latitude). The altitude of this city changes from 512 m to 1130 m the average altitude is about 821 m, it is distant about 110 km from the sea, the city is located at 1100 meters above sea level.

It is located in an area characterized by a cold winter with average temperatures around 80C and relative humidity trying 63% and a hot summer with average temperatures around 380C and can reach 450C see more, with relative humidity around 38%.

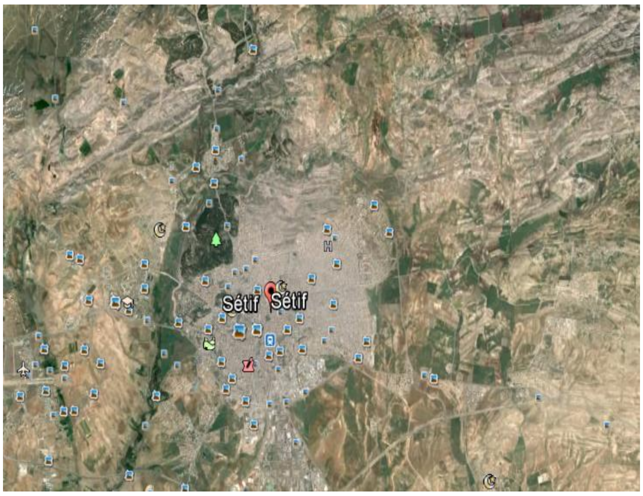

Figure 1. Geographical location of the city of Setif

Sizing of a hybrid system

Sizing of photovoltaic generator

For PV systems that operate much more during the high seasons, the orientation of the panels is towards the south with the modules tilting close to the horizontal.

In its general form the crankshaft power of the generator (Pc) is determined according to the following Eq. [1]:

$$P_c = \frac{E_{elect}}{N_{HE} \times K} \tag{1}$$

Where: N_{HE} - the average daily monthly value, K - constant which takes into account the losses which are due essentially to the losses at the level of the PV field (dirt of the panels, at the terminals of the diodes); presences of the regulators and the presence of the battery, E_{elect} - energy produced per day (Wh/day).

The current-voltage characteristic illustrated in Table 1 describes the behaviour of the solar panel used under the influence of specific weather conditions (illumination level G = 1000 W/m^2 and ambient temperature T=25°C).

Table 1. Analysis of the results of the hybrid system

Parameters	Value
Maximum power	62W
Short circuit current	5.9 A
Open circuit voltage	80 V

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Current at the maximum power point	4.8 A
Voltage at the maximum power point	62 V
Resistance series	0.008 Ω
Temperature coefficient	0.0024

We apply the equation (1), the power of the PV generator is 7.59 KWc.

Sizing of a wind turbine

The wind turbine turning by a nominal generator is 15 KW, the turbine of the wind turbine drives a Squirrel-cage Ind. Machine, and we assume that its yield equal to equal 0.8 (without multiplication). Now, we will do mathematical calculations to choose the dimensions of the wind turbine, Eq. [2].

$$P_t = \frac{P_u}{n_g} \tag{2}$$

Where: P_t - Power of the turbine, P_u - useful power, n_g - generator efficiency (0.8).

Sizing of the air motor

The values of the wind speed for the Setif site for each month and during the year are given by the following Table 2:

Table 2. Wind speed in Setif

Month	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
V_v (m/s)	5.22	5.32	5.30	5.34	4.52	4.33	4.46	4.36	4.17	4.48	5.15	5.33

The average value of the wind speed equals 4.83 m/s.

Sizing of diesel generator

The choice of the power of the diesel generator DG depends on the power of the site, consumption peaks and devices used.

- The power rating of the DG must be higher than the average power consumption of the site, in order not to risk an overload to the device and its irreversible damage. On the other hand, taking too big induces a great fuel consumption in relation to the needs.

- The power rating of the DG must be higher than the power of the peak and the starting power of some appliances (refrigerator, washing machine, drill).

Sizing of battery

The total capacity is the energy, in Ah, that the battery can store for a duration of the discharge of 100 h. It is given according to the depth of discharge, Eq. [3].

$$C_{100} = \frac{C_u}{P_D \times R_T} \tag{3}$$

Where: P_D - the maximum allowable depth of discharge (0.3), R_T - reducing coefficient of temperature (0.9).

Sizing of the conversion system (inverter)

The power of the inverter in the range, Eq. [4] [Pc* 0.9; Pc* 0.95].

$$6.83\ \text{KW} < P_{ond} < 7.21\ \text{KW} \tag{4}$$

Photovoltaic-wind-diesel hybrid power system

Hybrid power systems can consist of any combination of photovoltaic, wind, diesel, and batteries. Such flexibility has obvious advantages for customizing a system to a particular site's energy resources, costs and load requirements. In the present case, a photovoltaic- wind-diesel hybrid power system and a power converter is used to design and meet the load requirements of the village under investigation. The schematic diagram of the photovoltaic-wind-diesel hybrid model used in this study is depicted in Figure 2.

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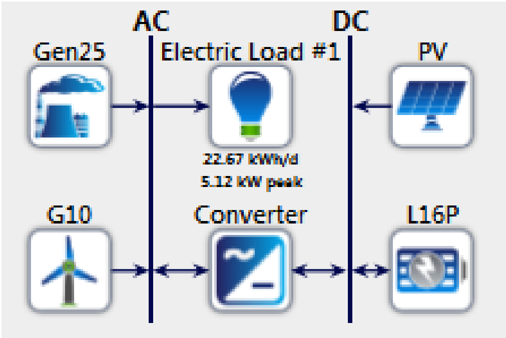

Figure 2. Photovoltaic-wind-diesel hybrid model used in the study

The hybrid power system optimization tool HOMER developed by NREL has been used in the present study. The flow chart showed in Figure 3 gives detailed steps of the proposed sizing optimization methodology.

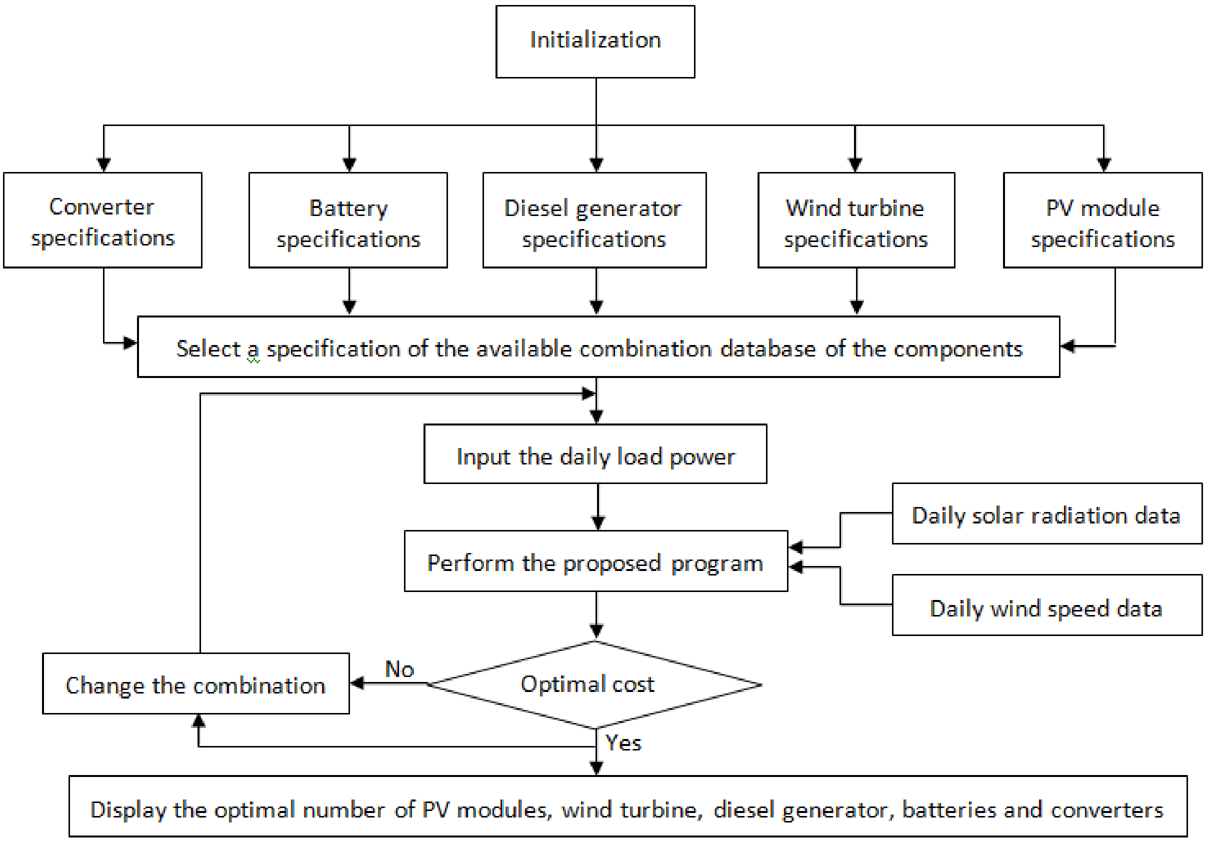

Figure 3. Flow chart of the proposed sizing optimization methodology

HOMER software hybrid power system modelling tool

HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote standalone and distributed generation applications. HOMER's optimization and sensitivity analysis algorithms allow the user to evaluate the economic and technical feasibility of a large number of technology options and to account for uncertainty in technology costs, energy resource availability, and other variables. HOMER models both conventional and renewable energy technologies.

Results and discussions

Our case deals with a simulation of a hybrid electric power generation system that contains two renewable photovoltaic and wind energy systems, and another diesel system, with the presence of batteries and converters, the system is autonomous network. In this case HOMER presents the simulation result as shown in the Table 3.

Table 3 shows all the feasible system configurations, because HOMER displays a list of system configurations that it found feasible for this project. They are listed in order (from top to bottom) from the most profitable to the least profitable. The cost-effectiveness of a system configuration is based on its current net cost PV/Wind/Diesel/Batteries/Converter is the most cost-effective design. Note that the best system used is the hybrid system, in the line.

Table 3. Calculation results for the hybrid system

Hybrid system	PV (KW)	Generic (10KW)	DG (KW)	L16P	Converter (KW)	COE ($)	NPC ($)	Production (KWh)
PV-Wind-DG-Battery-Converter	7.60	2.00	25.00	2.00	7.00	0.408	43.667	10.525
PV- DG-Battery-Converter	7.60		25.00	2.00	7.00	0.576	61.602	22.181
Wind-DG-Battery--Converter		2.00	25.00	2.00	7.00	0.597	63.851	20.012
PV-Wind-DG-Converter	7.60	2.00	25.00		7.00	0.825	88.559	29.231
PV- DG-Converter	7.60		25.00		7.00	0.943	100.80	38.538
DG-Battery-Converter			25.00	2.00	7.00	0.974	104.17	40.831
Wind-DG		2.00	25.00			1.07	114.74	41.588
DG-			25.00			1.28	136.40	54.750

We obtained the optimal result using the software (HOMER), Table 4:

Table 4. Optimal results for the hybrid system

PV (KW)	Generic (10KW)	DG (KW)	L16P	Converter (KW)	COE ($)	NPC ($)	Production (KWh)
7.60	2.00	25.00	2.00	7.00	0.408	43.667	10.525

From this result, we find that the ideal hybrid system used is one that contains: 7.6 KW of PV, 2 Generic 10 KW, 1 Generator 25 KW, 2 Trajan L16P and 7 KW Converter.

The total estimated cost over a year of work at all project costs (capital, replacement, O & M, fuel, salvage) is 43,667 $ with 0.408 $/KWh. The results have been distributed as shown in Figure 4.

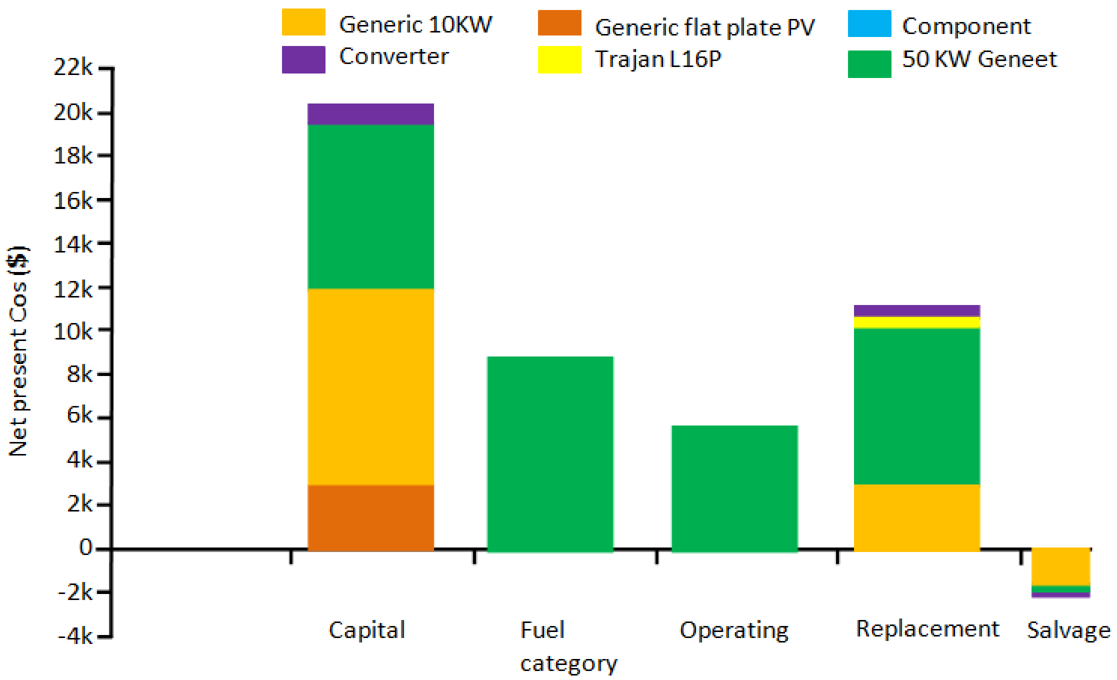

Figure 4. Cash flow summary for the hybrid system

We find the highest cost in the system used which is represented by the base price (capital) of 20,342$ followed by (replacement) of 1.1080 $, after (flut) of 8814$ and (salvage) from 2045 $.

The Figure 5 present the summary of operations and replacements throughout the life of the system We used the equipment back more than 20 years, we find that the project did not completely change all the devices as it was planned 20 years ago.

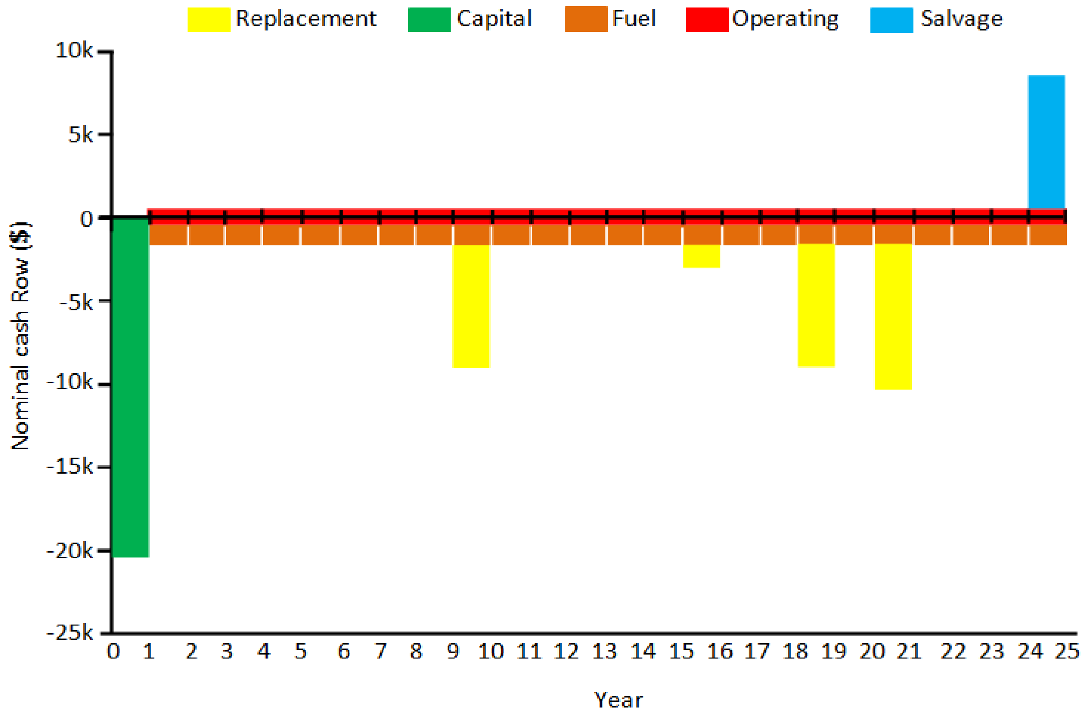

Figure 5. Summary of operations and replacements throughout the life of the system

Except with regard to a few small parts after about every 4 years on batteries that do not last more than 5 years and some small equipment.

Analysis of the electrical energy produced

Each generator produces energy individually. The energy produced from the optimal system is shown in the Figure 6 below.

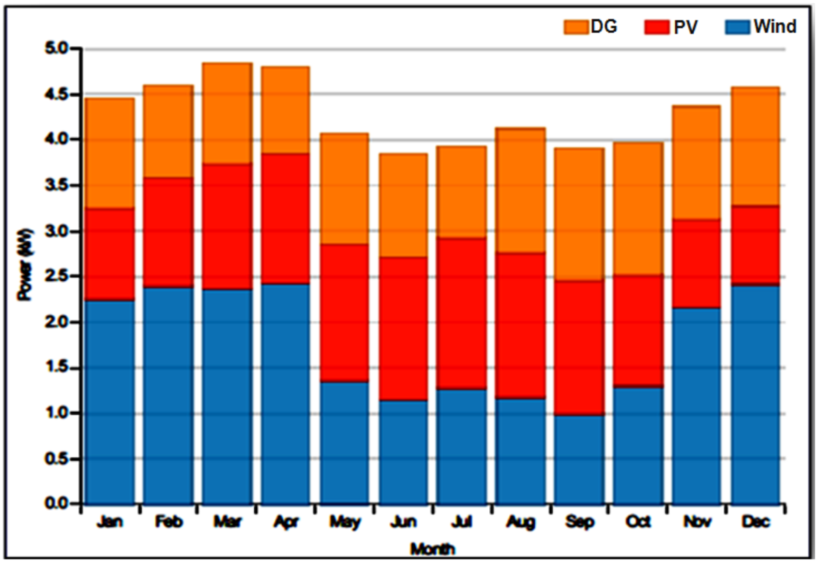

Figure 6. Average power produced by each source during a year

Table 5 shows the rate of electric power generation for each generator throughout the year.

Table 5. Analysis of the results of the hybrid system

Instruments	Production rate (%)	Quantity of energy (Kwh/year)	Running time (h/year)
Photovoltaic	30.6	11476	4372
Wind	41.33	15499	6064
Diesel generator	28.07	10525	1684

From Figure 6 and Table 5 it can be seen that the production of energy by the optimal hybrid system during a full year of operation has a continuity of energy production. We note that more than 70% of the energy is produced by renewable energy generators (41.33% or 15499 kWh/year for wind and 30.6% or (11476 kWh year for photovoltaic panels), something that participates to the reduction of the greenhouse effect for our planet Another remark noted is the variation of the energy production for each generator during the year, it appears that the wind generator participates with a big power produced in the season of autumn and winter, this power is decreasing with the decrease of wind speed in the spring and summer. However the production of photovoltaic generator increases by the presence of significant illumination. The production of the diesel generator is increased in the same effect to satisfy the energy demand of the load. The power generation study for each generator is illustrated as follows.

The diesel generator operates for a period of less than one-third of the year, with an average state of charge of 28.07%, of (10525 kWh/year), with an operating life of (1684 h/year).

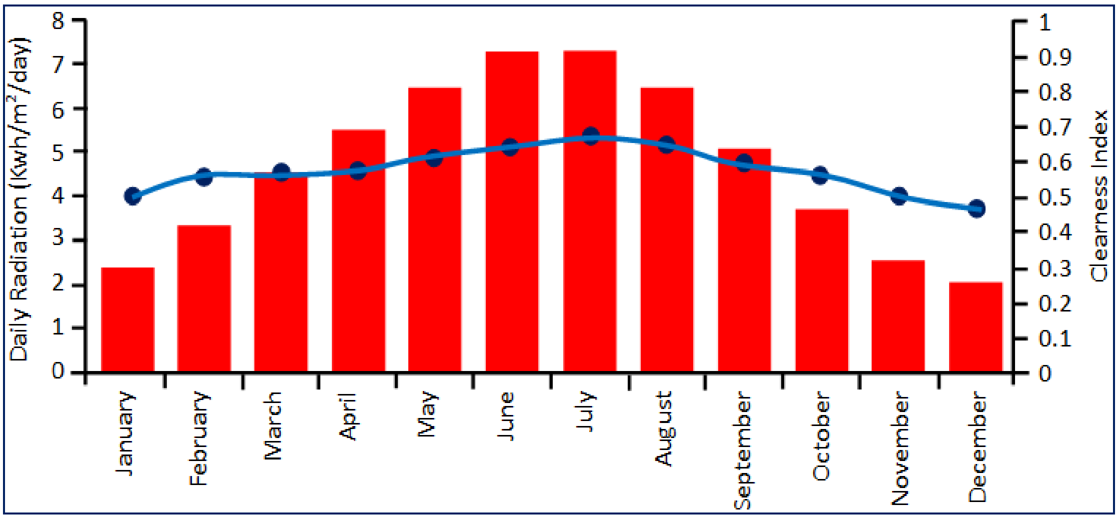

Figure 7. Monthly solar radiation

Featuring department of Setif to a semi-arid continental climate characterized by hot, dry summers and rainy winters with an acceptable amount and wind speed.

From Figure 7 it can be seen that the solar radiation reached their highest level in July (0.641) and each month (May, June, August) that were close being the same season. The lowest level of radiation appears during the month of December, which is the middle of winter.

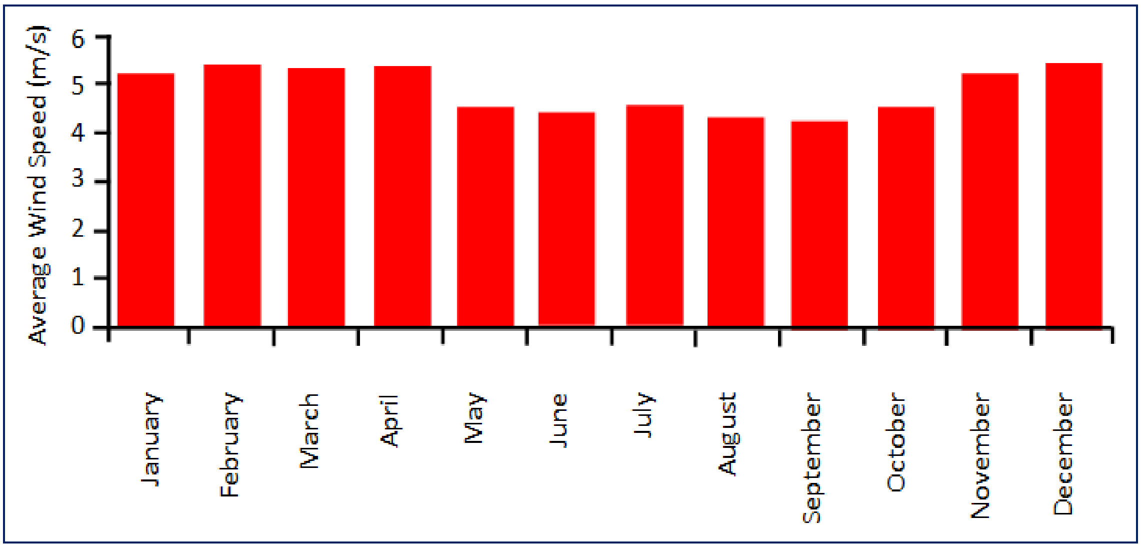

Figure 8. Monthly wind speed

From Figure 8 it can be seen that the largest amount of renewable energy produced by the wind turbine can be found in the months of December, February and April. Due to the wind speed influenced in the following way (December 5.33 m/s, February 5.32 m/s and April 5.34 m/s).

Photovoltaic generator (PV)

Figure 9 presents a DMAP presentation of energy production by the photovoltaic generator, this type of graph highlights a year of hourly data, each hour of the year is presented by a colour that simulates a precise information of a value of data. This presentation makes it possible to see more clearly the useful information for an easy and concrete interpretation.

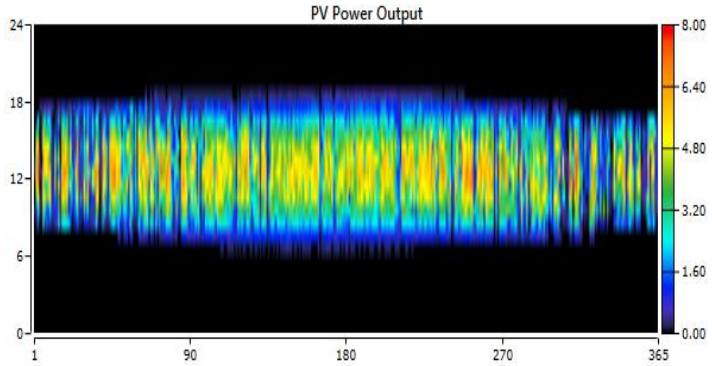

Figure 9. Total amount of daily energy produced by PV for one year

It should be noted that the period of operation of photovoltaic generator is limited in the winter months between 7 am in the morning and 17h, and conversely in the summer season this limit is stabilized between 6 in the morning until 18h. Photovoltaic generator production is zero in the peak hour according to the daily load profile at 20h, which introduces in parallel the operation of other generators or the use of energy stored in the batteries to meet the load demand.

Wind

As shown in Figure 10, the wind generator runs all day, which is well shown in the DMAP graph.

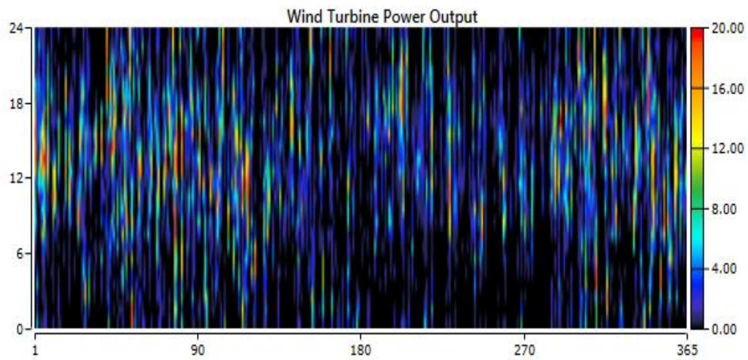

Figure 10. Quantity of total daily energy produced by the wind turbine for one year

The production of electrical energy from the wind turbine is low in winter because the wind is limited between (10h and 18h), compared to other months of the year during which the production changes from 0 to 20 KW and it reaches the highest value in the months of April and August (about 19.8 KW). For a total operating time of approximately 6064 hrs/year at a price of 0.05$/KWh

Diesel generator (DG)

The analysis of the duration of production of electrical energy at (DG) is found the same throughout the year, Figure 11.

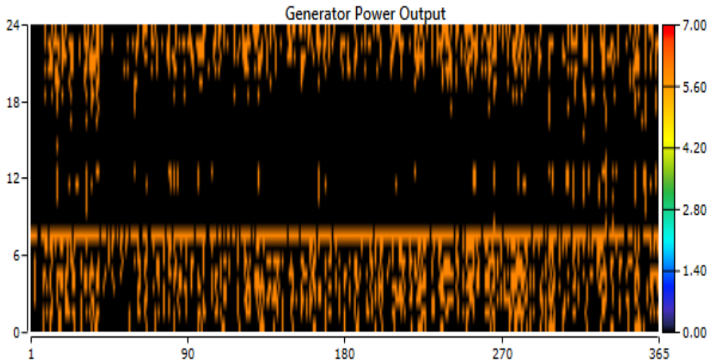

Figure 11. Quantity of total daily energy produced by the diesel generator for one year

The generator works in parallel with the storage batteries. It starts at the end of the day (at sunset) and continues until sunrise due to the lack of renewable energy (sun and wind). The production of this electrical energy up to (6.3 KW), for a total operating time of 1984 h / year at a price of 0.89 $/kWh.

Storage batteries

The battery is an important and fundamental part of this economical system of electrical energy and is used permanently throughout the day, where its charge level is between (30 and 100%) during the days of the year (Figure 12).

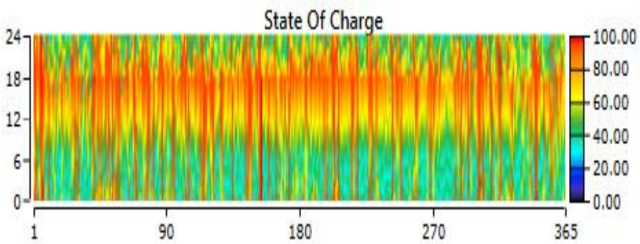

Figure 12. Using the battery charge through a year

Conclusions

In this paper, the sizing of a hybrid system photovoltaic/wind/diesel was implanted, by estimating the daily energy potential available and the power demanded by the user. The comparative technical and economical simulation results shows the importance of hybrid systems adopting renewable energy sources for securing power supply to electrical loads in remote areas. Based on the comparative simulation carried using HOMER software, the hybrid system labelled cases 1 (photovoltaic/wind/diesel/battery) is chosen as optimal system design. The hybrid system in this cases is more reliable in terms of feeding preferences and continuity of electrical power supply as discussed earlier. The study showed the importance of the addition of a conventional diesel generator to the components of hybrid system, not as an option but to ensure the continuous feeding of the electrical loads in some rare but critical condition especially for remote areas far from electrical grid.

References

1. IEA, *Measuring progress towards energy for all: power to the people*, World Energy Outlook (International Energy Agency), 2012.
2. Bhattacharyya S.C., *Energy for sustainable development a critical review and analysis,* Energy for sustainable Development, 2012, 16 (3), p. 260-271.
3. Hassan Q., Jaszczur M., Abdulateef J., *Optimization of PV/wind/diesel hybrid power system in HOMER for rural electrification*, Journal of Physics: Conference Series 745, 2016, 032006.
4. Colle S., Abreu S.L., Ruther R., *Economic evaluation and optimisation of hybrid diesel/photovoltaic systems integrated to electricity grid*, Sol Energy, 2004, 76, p. 295–299.
5. Kanase-Patil A.B., Saini R.P., Sharma M.P., *Sizing of integrated renewable energy system based on load profiles and reliability index for the state of Uttarakhand in India,* Renewable Energy, doi:10.1016/j.renene.2011.04.022, 2011.
6. Chellali F., Khellaf A., Belouchrani A., Recioui A., *A contribution in the actualization of wind map of Algeria*, Renewable and Sustainable Energy Reviews, 2011, 15, p. 993–1002.
7. Dihrab S.S, Sopian K., *Electricity generation of hybrid PV/wind systems in Iraq*,

Renewable Energy, 2010, 35, p. 1303-1317.

8. Nfah E.M., Ngundam J.M., Tchinda R., *Modelling of solar/diesel/battery hybrid power systems for far-north Cameroon*, Renewable Energy, 2007, 32, p. 832-44.
9. Saheb-Koussa D., Haddadi M. and Belhame M., *Economic and technical study of a hybrid system (wind–photovoltaic–diesel) for rural electrification in Algeria*, Applied Energy, 2009, 86, p. 1024–1030.
10. Connolly D., Lund H., Mathiesen B.V. and Leahy M., *A review of computer tools for analysing the integration of renewable energy, into various energy systems*, Applied Energy, Elsevier Ltd, 2009.